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SPECTRAL RADIATION INVOLVED IN PHOTOREACTIVATION OF ULTRAVIOLET-IRRADIATED CULTURES OF MICRO-ORGANISMS

BY

T. KNOWLES[1] AND A. H. TAYLOR[1]

The phenomenon of the photoreactivation of ultraviolet (2537 Angstroms or λ2537) irradiated micro-organisms reported by Kelner (1, 2),[2] 1949, later by Novick and Szilard (3) and confirmed by others has spurred investigation into the possible antagonistic actions of specific spectral regions of radiant energy. The following series of tests was made to determine those spectral regions responsible for this phenomenon of photoreactivation.

METHODS

Twenty-four hour cultures of *Escherichia coli* were used. These were diluted in normal saline to make a 1:100 suspension. This suspension was nebulized with a DeVilbiss No. 40 nebulizer onto inverted culture plates containing Difco tryptose blood agar base medium. The inverted plates were held about one inch from the orifice of the nebulizer which was operated at a pressure of 5 psi. The plates were moved in a circular motion for one minute each in order to give a fairly uniform distribution of organisms.

After seeding, the plates were partly exposed to the radiant energy emitted by a bare 15-watt General Electric germicidal tube. The intensity of ultraviolet energy of λ2537 used was 200 microwatts per sq. cm., which was obtained at a distance of 14 in. from the surface of the germicidal tube. This measured intensity energy E, times the exposure in minutes t, determines the dosage, Et.

The spectral region of photoreactivating radiant energy was first investigated by the use of various sources and filters. By proper selection of filters, the cultures could be irradiated by radiant energy of narrow spectral ranges.

[1] Lighting Research Laboratory, General Electric Company, Nela Park, Cleveland, Ohio.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

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The photoreactivation effect of the radiant energy transmitted by the filters was studied by the use of a 500-watt tungsten-filament lamp projector. The double condensers were used, but not the objective lens. This gave a fairly uniform intense circular spot 1.75 in. in diameter and having an intensity of 40,000 to 50,000 footcandles of white light before a filter was interposed. Other sources of illumination were a quartz mercury arc, 4500° K fluorescent tubes, 1000-watt tungsten general-service floodlamp and northwest skylight.

For the absorption of the infrared, two methods were used satisfactorily. These were a 3.2-cm. depth of 0.03 *N* aqueous $CuCl_2$ as described by Kelner and a single and double layer of AKLO heat-absorbing glass. Obviously, the advantage of the glass is that it can be used in any position.

By the introduction of filters over all or part of the beam, the relative photoreactivation of various spectral bands could be observed. The filters used were red, orange, yellow, green, blue and Wratten 2A ultraviolet absorbing filter. The spectral range of transmission of these filters is illustrated in Fig. 1.

The tungsten lamp and mercury arc spectra were dispersed by means of a large quartz spectrograph. The slit of the spectrograph was opened to 0.3 mm. for exposures to a panchromatic photographic plate and 3.0 mm. for exposures to culture plates. These latter were 4- by 10-in. glass plates with a layer of B.A.B. medium on one surface. The 3.0-mm. slit disperses the monochromatic mercury lines to make spectral bands of radiation (Fig. 1). Culture plates were seeded in the same manner as already described for petri dishes. One half of the culture plate was exposed to germicidal energy of λ2537 of a dosage of 150 *Et*, leaving the unirradiated portion of the plate as a control. These were placed in the photographic plate holder of the spectrograph in such a manner that the dispersed spectral radiant energy from the prism fell only on the previously ultraviolet-irradiated portion of the culture plate. By this method individual portions of a homogeneously seeded culture plate were exposed to monochromatic radiant energy of various wavelengths. These we have termed "culture spectrograms." Exposures ranged from 4 to 16 hr., followed by incubation at 37° C. until colonies were large enough to photograph, usually 12 to 18 hr. The effects of the tungsten spectrum extending from λ3300 to λ7000 and the mercury-arc spectrum from λ2537 to λ7000 were observed by this technique.

The third study was the relative photoreactivation produced by high intensities of radiant energy from three sources with different spectral characteristics. The sources used in this case were an ordinary 1000-watt tungsten-filament lamp, a regular 4500° K fluorescent tube and northwest skylight through common window glass $\frac{1}{8}$-in. thick. The culture dishes were so arranged that the illumination was the same in all three cases, namely 200 footcandles, as measured with a light meter. The exposures were 4 hr. in duration.

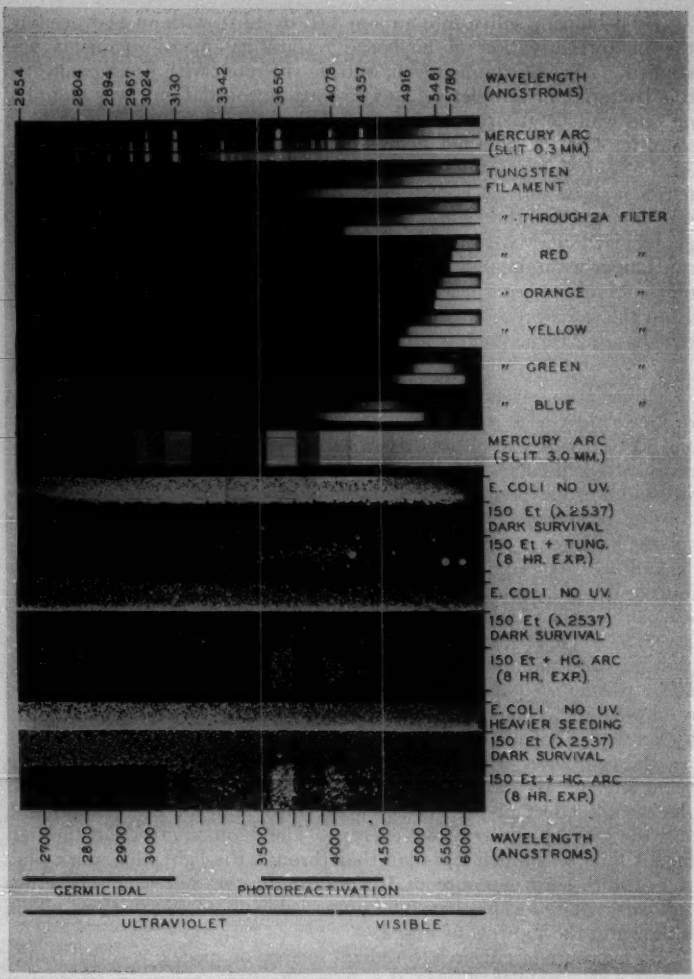

FIG. 1. Each series of three photographic spectrograms of a radiant energy source in the upper half of the illustration was obtained by a series of increasing exposures in the ratio of 1, 5 and 25 seconds. Only sources producing radiant energy in the spectral region of λ3500–λ4500 will produce significant photoreactivations. Lower half of the illustration shows bacterial spectrograms, one made by exposure to tungsten-filament radiation and the lower two to a quartz mercury arc with two concentrations of *E. coli* infections of the culture plate. Photoreactivation of the ultraviolet (λ2537) irradiated *E. coli* organisms is apparent in the spectral region λ3500–λ4500.

By nebulizing saliva into a room 8 ft. by 12 ft. with an 11-ft. ceiling, the photoreactivation of air-borne respiratory micro-organisms was studied. Air was sampled from outside the room with hoses connected to a bacterial air-sampler (4). A 15-watt germicidal unit was mounted on one wall 6½ ft. from the floor. The room illumination was from six 6-ft. 4500° K slimline fluorescent tubes mounted on the ceiling. At the bacterial sampling-levels of 4 and 8 ft. from the floor, the illumination was 50 and 150 footcandles, respectively. The air in the room was infected by the nebulizer for 10 minutes. After infection, the germicidal unit was turned on and bacterial air-samplings were made continuously throughout a period of 2 hr. Tests were first made with no room light excepting that produced by the 15-watt germicidal unit. Then the same procedure was repeated with the high-intensity fluorescent lighting turned on.

RESULTS

Observations were made of the photoreactivation in a number of surface irradiated *E. coli* culture plates using ultraviolet (λ2537) dosages of 100 to 600 *Et*. Cultures receiving over 250 *Et* showed little or no recovery when exposed to the radiant energy from the 500-watt tungsten-lamp projector. The optimum photoreactivation was observed on cultures receiving 150 *Et* of λ2537 radiant energy on the surface of the culture medium.

Cultures exposed to the photoreactivating radiant energy transmitted by red, orange, yellow and green filters showed no revival whereas cultures exposed through blue filters showed considerable recovery. Repeated tests were made which definitely showed that the photoreactive radiant energy was transmitted by a Corning signal blue filter, No. 556. This blue filter transmits a high percentage of long-wave ultraviolet energy produced by a mercury arc and particularly the energy of λ3650.

The next filter tried was a Wratten 2A which has no transmission below λ4000. By interposing this ultraviolet-absorbing filter, we could observe the effect of the visible energy only and not the visible light plus the long-wave ultraviolet energy. The photoreactivation through the 2A filter was much less than that through the light blue, dark blue or no filter. An exposure of 10 minutes to the 500-watt projection unit was required to produce minimum visible photoreactivation. This is shown in the top row of Fig. 2.

By exposure of cultures to radiant energy of specific spectral bands it was now established that the most effective energy in producing reactivation of *E. coli* is not in the visible spectrum but is primarily in the long-wave ultraviolet region adjacent to the short-wave limit of the visible spectrum.

The next step included the use of the quartz spectrograph in order to determine what part of the ultraviolet spectral region produced

photoreactivation. Bacterial culture spectrograms were made with tungsten-filament and mercury-arc sources. The tungsten lamp, producing a continuous energy spectrum from about λ3300 and up into the visible region, indicated photoreactivation throughout the range

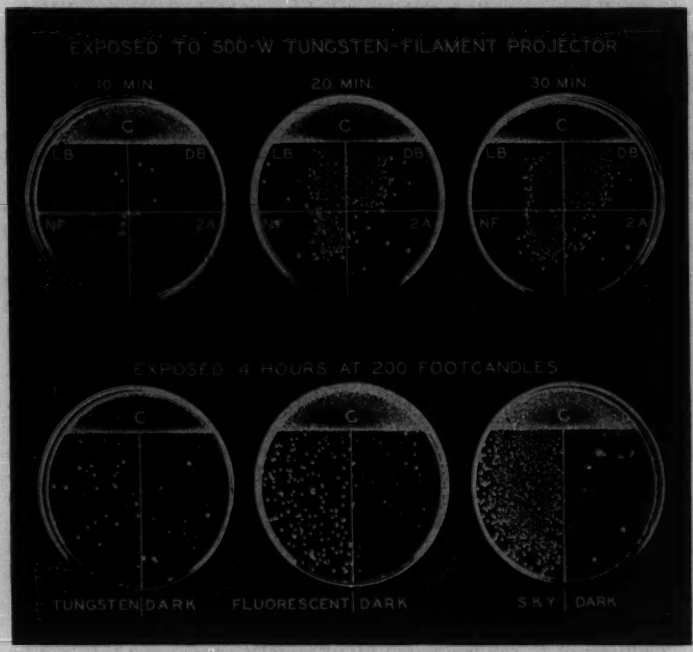

FIG. 2. These culture plates were first seeded with *E. coli* and the lower three-quarters of each plate was exposed to ultraviolet (λ2537) radiant energy. The upper quarter of each plate marked "C" is the unirradiated control. The three plates in the top row show the relative photoreactivation effected by the light from the 500-watt tungsten-filament projector unit when exposed through a light blue (LB), dark blue (DB), Wratten 2A (2A), and no filter (NF) for exposures of 10, 20 and 30 minutes (note spectrograms of these filters in Fig. 1).

Photoreactivation of ultraviolet irradiated (λ2537) *E. coli* on the left half of each of the lower three plates was obtained by four hour exposures at 200 footcandles of illumination from a tungsten-filament lamp, 4500° K fluorescent lamp and skylight. The right-hand side of each plate was shaded from the reactivation source and indicates the dark survival.

from λ3500 to λ4500. When using the mercury arc, the reactivation appeared to be greatest for energy of λ3650, less for λ4078, and least for λ4358. There is a marked degree of bacterial inhibition by the energy at λ3130 and complete inhibition by energy shorter than λ3022.

The λ4358 energy from the mercury-arc source is more intense than energy of λ4078, but indications are that λ4358 is the less effective in producing reactivation of *E. coli*. Photos of cultures exposed in the quartz spectrograph are shown in Fig. 1.

It is now obvious (Fig. 1) why no photoreactivation was observed when red, orange, yellow and green light was used, the spectral transmission of all of these filters being above the photoreactivation region of λ3500 to λ4500. The blue filter, having a transmission well below λ4000, transmits the more effective photoreactivating radiant energy (Fig. 1).

A study was made of the effect of high levels of indoor illumination from tungsten-filament lamps, 4500° K fluorescent tubes, and natural skylight through glass windows. After the plates were seeded on the surface of the nutrient agar and partly irradiated by λ2537 energy to dosages of 150 *Et*, plates were exposed for 4 hr. to an intensity of 200 footcandles from each of the three sources. In Fig. 2 (bottom row) are shown some representative cultures from this test. Based on the revival in the plates exposed to each of the three sources, the relative reactivating effectiveness was 1, 3 and 13 for the three sources, tungsten lamp, 4500° K fluorescent and natural skylight, respectively. These ratios are generally in accord with the amount of energy emitted by each of the three sources in the spectral region from λ3500 to λ4500.

Air-borne respiratory micro-organisms were exposed continuously to ultraviolet energy (λ2537) in a dark room and also with the room illuminated to 50 and 150 footcandles at the 4- and 8-ft. sampling-levels, respectively. After two hours of exposure to the germicidal ultraviolet energy and to 150 footcandles of illumination, air-sampling showed a bacterial survival of less than 0.5 per cent. Similar tests conducted in almost complete darkness also showed a similar survival of less than 0.5 per cent.

SUMMARY

Cultures of *E. coli* irradiated by ultraviolet energy of λ2537 can be partially reactivated by visible blue light from λ4500 to λ3800. Reactivation becomes most evident in the long-wave ultraviolet in the region of λ3650 or the so-called "black light" band of the mercury spectrum.

These results are primarily qualitative. The use of color filters to isolate various bands of tungsten spectra in addition to obtaining monochromatic energy by means of a quartz spectrograph tend to place the region of maximal photoreactivity between λ3500 and λ4500.

Simultaneous irradiation of air-borne respiratory micro-organisms with λ2537 ultraviolet and with visible light and near-ultraviolet energy from 4500° K fluorescent tubes showed no significant or measurable reactivation by the latter, even though the illumination was much higher than that generally prevailing indoors.

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(3) NOVICK AND SZILARD, "Genetics," *Proc. Natl. Acad. Sci.*, Vol. 35, pp. 592–595 (1949).

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Kodak Optical-Gaging Projector (*American Machinist*, Vol. 95, No. 12).—This machine projects a greatly enlarged shadow or a surface reflection of any object placed in its staging field onto a large, illuminated screen. It permits quick visual checking of the part against detailed drawings or other specification data previously placed over the viewing screen. It is specifically for production-line inspection.

That the projector can be used for this purpose is attributed to its small size and its optical system. The system allows an unvarying 8 in. of space between lens and object for all magnifications up to 100. This permits use of staging fixtures that automatically key projected objects to a tolerance chart which may be accurately positioned over the projection screen.

The projector body, the work table, and the lamp house can all be separated for attachment to bigger fixtures used in optical gaging of large equipment.

Known as the Model 3, the projector has an accessory by which light can be sent out of the same lens that picks up the image. In this way, surfaces and deep recesses that cannot be shadow projected can be examined. Either surface or shadow projection is possible for objects facing toward the lens, up, down, to the left, or to the right. The projector is manufactured by Eastman Kodak Company.

Thermostat Is Hermetically Sealed (*Product Engineering*, Vol. XXII, No. 6).—New small snap-action, hermetically sealed disk type thermostats are weatherproof and waterproof. The terminals are brought out through glass seals. Rubber is bonded over the terminals and to the rubber covered leads. For extremes of temperature, silicone rubber can be used in the molding and on the leads.

Transmission of the temperature to be controlled to the disk thermal element within the hermetic enclosure is obtained by mounting the disk in the bottom of the metal enclosure where it closely follows the temperature of any surface on which the thermostat is mounted or of air or liquids to which the bottom of the thermostat is exposed.

The disk type snap-action gives a positive switch action which withstands vibration, shock and motion. Designed originally for electric refrigerator automatic defrost control, these thermostats are expected to have many uses in both military and civilian equipment.

The switch action may be either single or double throw, single pole. Contacts are protected from all contaminants by the hermetic enclosure into which an atmosphere of helium or other inert gas can be sealed when desired. Temperature settings are factory preset and are not thereafter adjustable. Differentials between opening and closing temperatures range upward from 15 F. Electrical ratings are 10 amperes, 30 v d-c. and 125 v a-c., 3 amperes 250 v a-c. Manufactured by Spence Thermostat Div., Metals and Controls Corp., Attleboro, Mass.

THE INTEGRAL-EQUATION SOLUTION OF THE DAYLIGHTING PROBLEM

BY

DOMINA EBERLE SPENCER[1] AND VINCENT J. STAKUTIS[2]

In designing the luminous environment for classroom, factory, office, or home, one must consider methods of predicting both artificial and natural lighting. The development of the interflection method (1)[3] has made possible the prediction of the helios distribution and appearance of any artificially lighted room. But the calculation of daylighting is not in any such satisfactory state.

Previous methods of predicting the distribution of daylight in rooms have suffered from two major defects: (1) the sky has been assumed to be of uniform helios; and (2) interflections of light have been neglected. But skies are by no means uniform and modern directional glass block is not perfectly diffusing. The modern trend toward high room reflectances (2) improves the distribution and makes the contribution from reflected light of major importance at the back of the room.

Herman (3), Yamauti (4), Higbie (5), Waldram (6) and others have devised methods of calculating direct light from rectangular windows, but all of these workers have assumed uniform sky helios and have neglected interflections. The non-uniform sky was considered by Moon and Spencer (7), who utilized the actual cosine distribution for the uniformly overcast sky but omitted interflections. Greene (8) has attempted to include the effect of interflections by successive application of the Higbie formulas for rectangular windows. Greene's work is limited by the fact that it does not take into account all the interflections and decomposes the room into uniform rectangular sources.

The present paper applies the integral-equation method (as developed by Buckley (9), Moon (10), and Moon and Spencer (11)) to daylighting problems. The general interflection problem is formulated for very long rooms with windows on one wall. A complete solution is then developed for the special case of a perfectly diffusing window on one wall. These results are applicable to rooms lighted by diffusing glass blocks.

1. THE INTEGRAL EQUATIONS FOR DAYLIGHTING

The daylighting problem is inherently much more complex than the artificial-lighting problem, because the resultant distribution possesses

[1] University of Connecticut, Storrs, Conn.; formerly, Brown University.

[2] Department of Physics, Brown University, Providence, R. I.

[3] The boldface numbers in parentheses refer to the references appended to this paper.

less symmetry. In this paper, the general problem is simplified by considering only very long rooms with windows along one wall. Then, the distribution of light in the room can be expressed in terms of a single variable.

If the room is infinitely long, the light distribution is completely characterized by considering a cross section (Fig. 1). The height of the room is h and the width is w. The window extends along the left side of the room and is assumed to have negligible reflectance. The helios of the back wall H_1 is a function of the distance u_1 from the ceiling, while the helios of the ceiling H_2 and the floor H_3 depend on the distances u_2 and u_3 from the window. Average reflectances of back wall, ceiling, and floor are ρ_1, ρ_2, and ρ_3 and the surfaces are assumed to be perfectly diffusing.

If there were no interflections of light in the room, the helios of wall, ceiling, and floor would be

$$\begin{aligned} H_{01}(u_1) &= \rho_1 D_{01}(u_1), \\ H_{02}(u_2) &= \rho_2 D_{02}(u_2), \\ H_{03}(u_3) &= \rho_3 D_{03}(u_3), \end{aligned} \tag{1}$$

where D_{01}, D_{02}, and D_{03} are values of incident pharosage produced by light coming directly from the window. This distribution of light is, however, modified by interflections. The actual values of helios considering all interflections, are obtained from the integral equations,

$$\begin{aligned} H_1(u_1) &= \rho_1\Big[D_{01}(u_1) + \int_0^w H_2(v_2)K_{21}(u_1, v_2)\,dv_2 \\ &\qquad + \int_0^w H_3(v_3)K_{31}(u_1, v_3)\,dv_3\Big], \\ H_2(u_2) &= \rho_2\Big[D_{02}(u_2) + \int_0^w H_1(v_1)K_{12}(u_2, v_1)\,dv_1 \\ &\qquad + \int_0^w H_3(v_3)K_{32}(u_2, v_3)\,dv_3\Big], \\ H_3(u_3) &= \rho_3\Big[D_{03}(u_3) + \int_0^w H_1(v_1)K_{13}(u_3, v_1)\,dv_1 \\ &\qquad + \int_0^w H_2(v_2)K_{23}(u_3, v_2)\,dv_2\Big], \end{aligned} \tag{2}$$

where the *kernels*,

$K_{ij}(u_j, v_i)$ = incident pharosage at point u_j (produced by light from an infinite strip of width dv_i and helios H_i at point v_i) per unit helios, per unit width of strip.

The kernels are obtained by a direct application of the *unit-sphere method* of calculating incident pharosage (12). The kernels appearing

in Eq. 2 may be expressed as follows:

$$K_{12}(u_2, v_1) = \frac{\left(\frac{u_2}{h}\right)\left(\frac{w - v_1}{h}\right)}{2h\left[\left(\frac{u_2}{h}\right)^2 + \left(\frac{w - v_1}{h}\right)^2\right]^{\frac{1}{2}}},$$

$$K_{21}(u_1, v_2) = \frac{\left(\frac{u_1}{h}\right)\left(\frac{w - v_2}{h}\right)}{2h\left[\left(\frac{u_1}{h}\right)^2 + \left(\frac{w - v_2}{h}\right)^2\right]^{\frac{1}{2}}},$$

$$K_{13}(u_3, v_1) = \frac{\left(1 - \frac{u_3}{h}\right)\left(\frac{w - v_1}{h}\right)}{2h\left[\left(1 - \frac{u_3}{h}\right)^2 + \left(\frac{w - v_1}{h}\right)^2\right]^{\frac{1}{2}}}, \tag{3}$$

$$K_{31}(u_1, v_3) = \frac{\left(1 - \frac{u_1}{h}\right)\left(\frac{w - v_3}{h}\right)}{2h\left[\left(1 - \frac{u_1}{h}\right)^2 + \left(\frac{w - v_3}{h}\right)^2\right]^{\frac{1}{2}}},$$

$$K_{23}(u_3, v_2) = \frac{1}{2h\left[1 + \left(\frac{u_3 - v_2}{h}\right)^2\right]^{\frac{1}{2}}},$$

$$K_{32}(u_2, v_3) = \frac{1}{2h\left[1 + \left(\frac{u_2 - v_3}{h}\right)^2\right]^{\frac{1}{2}}}.$$

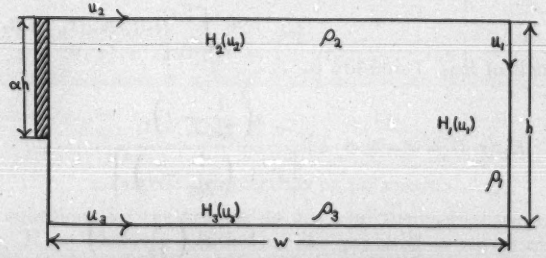

FIG. 1. A cross-section of a very long room.

It will be noted that Eqs. 2 and 3 contain only ratios of the room dimensions. They can be simplified by a suitable transformation of variables. To correlate the new development with previous work, the

domance of the room k, will be introduced:

$$k_r = \frac{h(l + w)}{2lw}.$$

If the room is very long, $l \to \infty$ and k_r becomes

$$k_r = \frac{h}{2w}. \tag{4}$$

Also introduce the new variables s and t:

$$\begin{aligned} s &= u/h, \\ t &= v/h. \end{aligned} \tag{5}$$

Once this change of variables is made, absolute dimensions of the room disappear entirely from the integral equations.

In terms of s and t, Eqs. 2 become

$$\begin{aligned} H_1(s_1) &= \rho_1\Big[D_{01}(s_1) + \int_0^{\frac{1}{2k_r}} H_2(t_2)K_{21}(s_1, t_2)\,dt_2 \\ &\qquad + \int_0^{\frac{1}{2k_r}} H_3(t_3)K_{31}(s_1, t_3)\,dt_3\Big], \\ H_2(s_2) &= \rho_2\Big[D_{02}(s_2) + \int_0^{1} H_1(t_1)K_{12}(s_2, t_1)\,dt_1 \\ &\qquad + \int_0^{\frac{1}{2k_r}} H_3(t_3)K_{32}(s_2, t_3)\,dt_3\Big], \\ H_3(s_3) &= \rho_3\Big[D_{03}(s_3) + \int_0^{1} H_1(t_1)K_{13}(s_3, t_1)\,dt_1 \\ &\qquad + \int_0^{\frac{1}{2k_r}} H_2(t_2)K_{23}(s_3, t_2)\,dt_2\Big]. \end{aligned} \tag{6}$$

The kernels of Eqs. 3 simplify to

$$\begin{aligned} K_{12}(s, t) = K_{21}(s, t) &= \frac{s\left(\frac{1}{2k_r} - t\right)}{2\left[s^2 + \left(\frac{1}{2k_r} - t\right)^2\right]^{\frac{3}{2}}}, \\ K_{13}(s, t) = K_{31}(s, t) &= \frac{(1 - s)\left(\frac{1}{2k_r} - t\right)}{2\left[(1 - s)^2 + \left(\frac{1}{2k_r} - t\right)^2\right]^{\frac{3}{2}}}, \\ K_{23}(s, t) = K_{32}(s, t) &= \frac{1}{2[1 + (s - t)^2]^{\frac{3}{2}}}. \end{aligned} \tag{7}$$

Further simplification is possible if the helios of the back wall is taken as constant. Equations 6 and 7 reduce to

$$H_1 = \rho_1\left[D_{01} + \int_0^{\frac{1}{2k_r}} H_2(t)K_{21}(t)\,dt + \int_0^{\frac{1}{2k_r}} H_3(t)K_{31}(t)\,dt\right],$$

$$H_2(s) = \rho_2\left[D_{02}(s) + H_1K_{12}(s) + \int_0^{\frac{1}{2k_r}} H_3(t)K_{32}(s,t)\,dt\right], \qquad (6a)$$

$$H_3(s) = \rho_3\left[D_{03}(s) + H_1K_{13}(s) + \int_0^{\frac{1}{2k_r}} H_2(t)K_{23}(s,t)\,dt\right],$$

and

$$K_{12}(s) = K_{13}(s) = \frac{1}{2}\left[1 - \frac{\left(\frac{1}{2k_r} - s\right)}{\sqrt{1 + \left(\frac{1}{2k_r} - s\right)^2}}\right],$$

$$K_{21}(t) = K_{31}(t) = \frac{1}{2}\left[1 - \frac{\left(\frac{1}{2k_r} - t\right)}{\sqrt{1 + \left(\frac{1}{2k_r} - t\right)^2}}\right], \qquad (7a)$$

$$K_{23}(s,t) = K_{32}(s,t) = \frac{1}{2[1 + (s-t)^2]^{\frac{1}{2}}}.$$

Frequently, the back wall is so full of openings (doors, or windows facing on a dark corridor) or of such low reflectance that its effect can be neglected. If in Eqs. 6 and 7 we assume that H_1 and ρ_1 are zero, then

$$H_2(s) = \rho_2\left[D_{02}(s) + \int_0^{\frac{1}{2k_r}} H_3(t)K_{32}(s,t)\,dt\right],$$

$$H_3(s) = \rho_3\left[D_{03}(s) + \int_0^{\frac{1}{2k_r}} H_2(t)K_{23}(s,t)dt\right], \qquad (6b)$$

where

$$K_{23}(s,t) = K_{32}(s,t) = \frac{1}{2[1 + (s-t)^2]^{\frac{1}{2}}}. \qquad (7b)$$

2. ANALYTIC APPROXIMATION OF THE KERNELS

The equations for the kernels do not lend themselves to easy integration. If an analytic solution of the problem is to be obtained, simple approximations for the kernels must be found, such that the areas under their graphs are approximately equal to the areas under the graphs of the actual kernels. Since daylighting would not be attempted in a room more than five times as deep as it is high, an approximation will be attempted only in the range $0 < s, t < 5$.

Perhaps the most important of the kernels is $K_{23}(s, t)$, which appears in all of the cases considered. The actual curve is shown in Fig. 2 where $K(s, t)$ is plotted as a function of $|s - t|$. It will be noted that the curve is approximated by a straight line, or

$$K_{23}(s, t) = K_{32}(s, t) \approx 0.40e^{-|s-t|}. \tag{8}$$

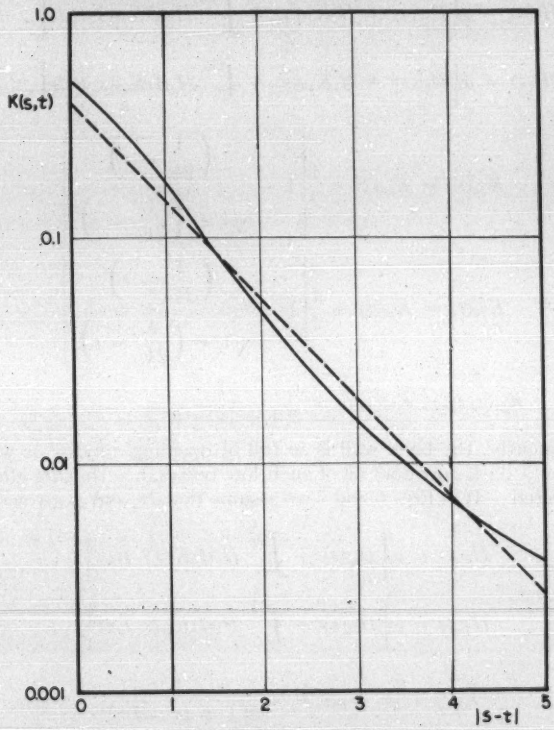

FIG. 2. The kernel $K_{23}(s, t) = K_{32}(s, t)$.
—— actual curve, Eq. 7*b*,
- - - - exponential approximation, Eq. 8.

A similar process gives the following approximate expressions for the remaining kernels:

$$\begin{aligned} K_{12}(s) &= K_{13}(s) \approx 0.35e^{-0.76\left(\frac{1}{2k_r} - s\right)} \\ K_{21}(t) &= K_{31}(t) \approx 0.35e^{-0.76\left(\frac{1}{2k_r} - t\right)} \end{aligned} \tag{9}$$

and

$$\begin{aligned} K_{12}(s,t) &= K_{21}(s,t) \approx 0.64e^{-0.82\left(\frac{1}{2k_r}+s-t\right)}e^{0.23s\left(\frac{1}{2k_r}-t\right)} \\ K_{13}(s,t) &= K_{31}(s,t) \approx 0.64e^{-0.82\left(1+\frac{1}{2k_r}-s-t\right)}e^{0.23(1-s)\left(\frac{1}{2k_r}-t\right)}. \end{aligned} \tag{10}$$

These approximations are believed to be sufficiently accurate so that they do not introduce errors of more than a few per cent in the final results.

3. SOLUTION OF THE INTEGRAL EQUATIONS

Consider the simplest case, where the back wall is neglected. The integral equations are

$$\begin{aligned} H_2(s) &= \rho_2\left[D_{02}(s) + \int_0^{\frac{1}{2k_r}} H_3(t)K_{32}(s,t)\,dt\right], \\ H_3(s) &= \rho_3\left[D_{03}(s) + \int_0^{\frac{1}{2k_r}} H_2(t)K_{23}(s,t)\,dt\right]. \end{aligned} \tag{7b}$$

Solution of Eqs. 7*b* is effected by a process of successive substitution. On the first substitution of the first equation into the second equation and conversely, we obtain

$$\begin{aligned} H_2(s) &= \rho_2 D_{02}(s) + \rho_2\rho_3\int_0^{\frac{1}{2k_r}} D_{03}(t)K_{32}(s,t)\,dt \\ &\quad + \rho_2\rho_3\int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}} H_2(\xi)K_{23}(t,\xi)K_{32}(s,t)\,dt\,d\xi, \\ H_3(s) &= \rho_3 D_{03}(s) + \rho_2\rho_3\int_0^{\frac{1}{2k_r}} D_{02}(t)K_{23}(s,t)\,dt \\ &\quad + \rho_2\rho_3\int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}} H_3(\xi)K_{32}(t,\xi)K_{23}(s,t)\,dt\,d\xi. \end{aligned} \tag{11}$$

Substitution of Eqs. 7*b* under the integral signs in Eq. 11 gives

$$\begin{aligned} \frac{H_2}{H} &= \rho_2\left(\frac{D_{02}}{H}\right) + \rho_2\rho_3 A_2 + (\rho_2)^2\rho_3 B_2 + (\rho_2\rho_3)^2 C_2 + (\rho_2\rho_3)^2 R_2, \\ \frac{H_3}{H} &= \rho_3\left(\frac{D_{03}}{H}\right) + \rho_2\rho_3 A_3 + \rho_2(\rho_3)^2 B_3 + (\rho_2\rho_3)^2 C_3 + (\rho_2\rho_3)^2 R_3, \end{aligned} \tag{12}$$

where

$$\begin{cases} A_2(s) = \displaystyle\int_0^{\frac{1}{2k_r}} \frac{D_{03}(t)}{H} K_{32}(s,t)\,dt \\ A_3(s) = \displaystyle\int_0^{\frac{1}{2k_r}} \frac{D_{02}(t)}{H} K_{23}(s,t)\,dt \end{cases}$$

$$\begin{cases} B_2(s) = \int_0^{\frac{1}{2k_r}} A_3(t)K_{32}(s,t)\,dt \\ B_3(s) = \int_0^{\frac{1}{2k_r}} A_2(t)K_{23}(s,t)\,dt \end{cases} \qquad (13)$$

$$\begin{cases} C_2(s) = \int_0^{\frac{1}{2k_r}} B_3(t)K_{32}(s,t)\,dt \\ C_3(s) = \int_0^{\frac{1}{2k_r}} B_2(t)K_{23}(s,t)\,dt \end{cases}$$

and

$$R_2(s) = \int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}} \frac{H_2(\mu)}{H} \times K_{23}(\eta,\mu)K_{32}(\xi,\eta)K_{23}(t,\xi)K_{32}(s,t)\,dt\,d\xi\,d\eta\,d\mu$$

$$R_3(s) = \int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}} \frac{H_3(\mu)}{H} \times K_{23}(\eta,\mu)K_{32}(\xi,\eta)K_{23}(t,\xi)K_{32}(s,t)\,dt\,d\xi\,d\eta\,d\mu.$$

The terms in R_2 and R_3 will generally be found to be negligible in comparison to the four previous terms of Eqs. 12. Thus the helios distribution on ceiling and floor is determined by evaluating D_{02}/H, A_2, B_2, C_2 and D_{03}/H, A_3, B_3, C_3 for a particular shape and type of window and for a particular shape of room. Reflectances enter only as coefficients of the above terms.

4. THE INITIAL PHAROSAGE DISTRIBUTION

The solution presented in Section 3 is valid for any initial distribution, whether it be from a clear window or any type of glass block. The simplest case is that in which the window is assumed to be perfectly diffusing and of uniform helios, and it is this case which will be treated in the remainder of the paper. The incident pharosage directly from the window (14) is

$$\begin{aligned} D_{02}(s_2,\alpha) &= \frac{H}{2}\left[1 - \frac{s_2}{\sqrt{s_2^2+\alpha^2}}\right], \\ D_{03}(s_3,\alpha) &= \frac{Hs_3}{2}\left[\frac{1}{\sqrt{(1-\alpha)^2+s_3^2}} - \frac{1}{\sqrt{1+s_3^2}}\right]. \end{aligned} \qquad (14)$$

When the expression appears under the integral sign, an analytic approximation is convenient:

$$\begin{aligned} D_{02}(s_2,\alpha) &\approx H(0.183)\,e^{0.926\alpha}e^{-[1.67-0.88\alpha]s_2}, \\ D_{03}(s_3,\alpha) &\approx H(0.032)\,e^{2.72\alpha}e^{-[0.46+0.37\alpha]s_3}. \end{aligned} \qquad (15)$$

If the effect of the back wall is to be included,

$$D_{01}(s_1, \alpha) = Hk_r\left[\frac{s_1}{\sqrt{1 + (2k_r s_1)^2}} + \frac{(\alpha - s_1)}{\sqrt{1 + (2k_r(\alpha - s_1))^2}}\right]. \quad (16)$$

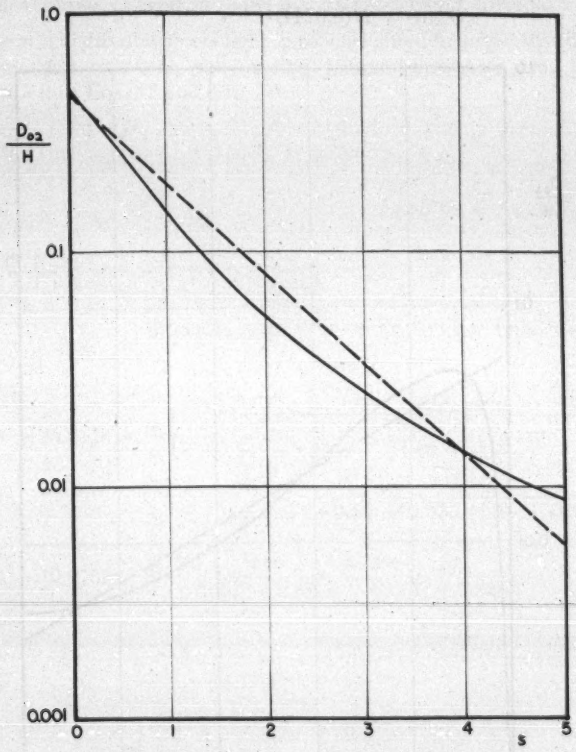

FIG. 3. Incident pharosage (without interflections) on ceiling from a perfectly diffusing window which covers the entire wall ($\alpha = 1$).
—— actual distribution, Eq. 14.
- - - - exponential approximation, Eq. 15.

The average incident pharosage $D_{01}(\alpha)$ on the back wall is

$$D_{01}(\alpha) = Hk_r \int_0^1 D_{01}(s_1, \alpha)\, ds_1$$

or

$$D_{01}(\alpha) = \frac{H}{4k_r}\left[\sqrt{1 + 4k_r^2} - \sqrt{1 + 4k_r^2(1-\alpha)^2} + \sqrt{1 + 4k_r^2\alpha^2}\right]. \quad (17)$$

Equation 7 is approximated by the expression,

$$D_{01}(\alpha) = H(0.0244)\, e^{1.35\alpha} e^{(1.24+2.51\alpha)k_r}. \quad (18)$$

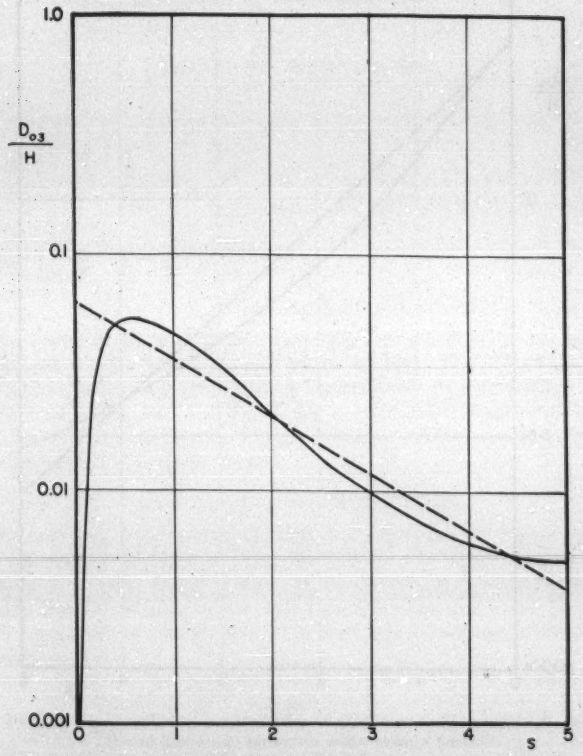

FIG. 4. Incident pharosage (without interflections) on floor from a perfectly diffusing window which runs one-fourth of the way down the wall ($\alpha = 1/4$).
—— actual distribution, Eq. 14.
- - - - exponential approximation, Eq. 15.

Accurate and approximate curves for D_{02} and D_{03} are shown in Figs. 3 and 4. Sufficient accuracy (better than 10 per cent) will generally

be obtained if the exponential approximations are employed under the integral signs while the accurate expressions are utilized where D_{6i} appears outside of an integral sign.

5. THE DISTRIBUTION OF LIGHT IN ROOMS LIGHTED BY PERFECTLY DIFFUSING WINDOWS

The actual distribution of light in rooms lighted by perfectly diffusing windows (and with back wall omitted) is found by substituting Eqs. 8, 14, and 5 into Eqs. 12 and 13:

$$\frac{H_2}{H} = \frac{\rho_2}{2}\left[1 - \frac{s}{\sqrt{\alpha^2 + s^2}}\right] + \rho_2\rho_3 A_2 + (\rho_2)^2\rho_3 B_2 + (\rho_2\rho_3)^2 C_2 + (\rho_2\rho_3)^2 R_2 \quad (19)$$

$$\frac{H_3}{H} = \frac{\rho_3 s}{2}\left[\frac{1}{\sqrt{(1-\alpha)^2 + s^2}} - \frac{1}{\sqrt{1+s^2}}\right] + \rho_2\rho_3 A_3 + \rho_2(\rho_3)^2 B_3 + (\rho_2\rho_3)^2 C_3 + (\rho_2\rho_3)^2 R_3$$

where

$$\begin{cases} A_2(s) = (0.0128)\, e^{2.72\alpha}\left[\dfrac{e^{-s}}{(-0.54 + 0.37\alpha)} - \dfrac{e^{s} e^{-\frac{[1.46+0.37\alpha]}{2k_r}}}{[1.46 + 0.37\alpha]} - \dfrac{2e^{-[0.46+0.37\alpha]s}}{(-0.54 + 0.37\alpha)(1.46 + 0.37\alpha)}\right], \\ A_3(s) = (0.0732)\, e^{0.925\alpha}\left[\dfrac{e^{-s}}{(0.67 - 0.88\alpha)} - \dfrac{e^{s} e^{-\frac{[2.67-0.88\alpha]}{2k_r}}}{[2.67 - 0.88\alpha]} - \dfrac{2e^{-[1.67-0.88\alpha]s}}{(2.67 - 0.88\alpha)(0.67 - 0.88\alpha)}\right], \end{cases}$$

$$\begin{cases} B_2(s) = 0.40 \int_0^{\frac{1}{2k_r}} A_3(t)\, e^{-|s-t|}\, dt, \\ B_3(s) = 0.40 \int_0^{\frac{1}{2k_r}} A_2(t)\, e^{-|s-t|}\, dt, \end{cases}$$

$$\begin{cases} C_2(s) = 0.40 \int_0^{\frac{1}{2k_r}} B_3(t)\, e^{-|s-t|}\, dt, \\ C_3(s) = 0.40 \int_0^{\frac{1}{2k_r}} B_2(t)\, e^{-|s-t|}\, dt, \end{cases}$$

$$R_2(s) = (0.0256)\int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}} \frac{H_2(\mu)}{H} \times e^{-|\eta-\mu|}e^{-|\xi-\eta|}e^{-|t-\xi|}e^{-|s-t|}\,dt\,d\xi\,d\eta\,d\mu,$$

$$R_3(s) = (0.0256)\int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}}\int_0^{\frac{1}{2k_r}} \frac{H_3(\mu)}{H} \times e^{-|\eta-\mu|}e^{-|\xi-\eta|}e^{-|t-\xi|}e^{-|s-t|}\,dt\,d\xi\,d\eta\,d\mu.$$

It will be noted that the series converge rather rapidly so that the R_2 and R_3 terms are small. It is believed that the errors incurred by utilizing the approximate kernels and omitting the remainder terms are less than those ordinarily encountered in photometric measurements of daylight.

7. CONCLUSIONS

This paper has presented a formulation of the problem of interflections in very long rooms lighted by daylight. The formal solution is also given for any type of window wall, whether it be constructed of clear glass or of diffusing or directional glass block. Numerical results have been worked out only in the case of a perfectly diffusing window and with the back wall of the room omitted. The results are significant for windows of diffusing glass or diffusing glass block. The application of these results is discussed in another paper (14).

It is hoped that further work will make possible the extension of the interflection method in daylighting to

(1) other windows, including the clear window lighted by an overcast sky and windows constructed from directional glass block,
(2) rooms with a highly reflecting back wall,
(3) the case of the room of finite length.

It would be desirable to continue this work until the daylighting problem with interflections can be formulated in as simple a fashion as the artificial lighting problem.

In conclusion we wish to thank the Pittsburgh-Corning Corporation, under whose sponsorship this work was carried out, and especially, Mr. Robert McKinley who suggested the project and Dr. D. D'Eustachio and Dr. Arvid Baker who cooperated in it. Our thanks are also due to two faithful computers, Mary Sullivan and James Lee.

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(12) See Chap. IV, Section 4.01, of *Lighting Design* (Ref. 1).

(13) See Chap. IV, Section 4.07, of *Lighting Design* (Ref. 1).

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Tiny Electronic Amplifier (*Electronics*, Vol. 24, No. 7.).—Bendix Radio Division of Bendix Aviation Corp., Baltimore 4, Md., has developed a tiny electronic amplifier for miniaturized airborne radar equipment. It is a band-pass type amplifier with a rated electrical gain of 130 db. Weighing less than 2 ounces and requiring only 35 component parts, its cost in large production quantities should be small enough to make feasible replacement of the entire amplifier in case of tube of component failure and because of its plug-in design replacement can be made in a matter of seconds.

Two new types of compasses developed by Army Engineer Research and Development Laboratory, Ft. Belvoir, Va., provide accurate readings in temperature range from minus 65 to 125 degrees F. A wrist compass only $\frac{3}{8}$" thick weighs less than 3 ounces, features osmium-alloy pivot and a sapphire jewel to reduce friction, polyethylene molded cover to hide visible light rays from luminous parts. The larger size lensatic compass, with luminous marks and indicator, permits nighttime azimuth readings with error of less than 2 degrees arc, is about two inches square and weighs only four ounces. Both types are in use in Korea.

Tailor-made weather simulates arctic, tropic and stratospheric conditions at the Engineer Research and Development Laboratories, Fort Belvoir, where temperature can be raised from −65 to 196 degrees F. in six hours, or pressure reduced to 35,000 feet altitude in half an hour. These conditions can be obtained in a heavy equipment test room 32 × 14 × 13 feet in which humidity can be varied from 20 to 100 per cent, and rain, snow, sleet, dew, fog and frost produced. Tests are run for Quartermaster, Signal, and Transportation Corps, the Air Force, and GSA; have included everything from bread baskets to bulldozers.

Plastics make a plane fly farther if used in the right place; the right place —auxiliary fuel tanks. Air Force engineers at the Power Plant and Aircraft Lab. at Wright-Patterson AFB are now working on such tanks, with standard nose and tail sections, which can be enlarged by simply inserting middle sections of various lengths; the whole tank is assembled by a tie rod running from nose to tail and leak-proofed by synthetic rubber seals around the joints. Eventual goal: interchangeable tank parts permitting use of anything from a T–33 trainer to a B–50.

New Heat-Resistant Alloy.—In line with the company's policy of conserving nickel supplies as far as possible during the current period of emergency, The International Nickel Company has announced the development of an alloy for use under conditions of high temperature and corrosion.

The new alloy, trade-named "Incoloy," contains about 35 per cent nickel and 20 per cent chromium, with the balance iron. It is produced in most standard rolling mill forms, including sheet, strip, rod, wire and tubing. This alloy is designed for many purposes now served by some of the company's older alloys, which run up to more than 70 per cent nickel.

CONTACT POTENTIAL DIFFERENCES *

BY

IMRE F. PATAI [1,2] AND MARTIN A. POMERANTZ [3]

I. INTRODUCTION

The potential differences and charges acquired by dissimilar materials in contact are related to phenomena observed at the very beginning of the history of experimental electricity. Although there never was any doubt regarding the reality of the potential differences which could be produced between insulators such as amber, glass, wood, wool, leather, etc., the existence of a potential difference between metals has been a controversial issue.

This effect was discovered and first measured by Volta in 1797. Such well-known figures as C. E. Maxwell, W. Ostwald, O. Lodge, and others thought that the true contact potential between pure metals is negligible, of the order of magnitude of the Peltier effect, amounting to some hundredths of a volt at most. The observed magnitudes of several volts were attributed to impurities such as adsorbed gas layers or thin layers of electrolytes adhering to the metallic surfaces. It is only in relatively recent times that a decisive state has been reached. Notable contributions toward this end were the experiments of Coehn (1)[4] and of Perucca (2), who revealed that reproducible measurements could be made, and the theoretical treatments of Sommerfeld (3) and Eckart (4), who predicted the existence of contact potential differences of the observed order of magnitude from purely physical considerations. Thus, although it was originally assumed that the explanation of contact potential must be based upon a treatment of chemical equilibrium involving electrochemical theories such as those of Helmholtz and Nernst, it was finally realized that the subject with which this paper is concerned constitutes an exclusively physical effect.

* This work was sponsored by the Office of Naval Research under Contract N8onr-651.

[1] Deceased; formerly, Physicist, Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

[2] It was with great sorrow that the Bartol Research Foundation lost, through death, the services of Dr. Imre F. Patai in January, 1949. Although Dr. Patai had been with the Foundation for only six months, the warmth of his personality had endeared him in the hearts of all of us, and it is a happy comfort for us to know that this feeling was reciprocated. The present paper has been prepared by Dr. Martin A. Pomerantz on the basis of notes left by Dr. Patai at the time of his death, and while it is only the beginning of what would have been an extended development had he lived, it does form a valuable unit of accomplishment in itself. [W. F. G. Swann, Director, Bartol Research Foundation of The Franklin Institute.]

[3] Physicist, Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

[4] The boldface numbers in parentheses refer to the references appended to this paper.

As in other phenomena of an allied nature, the surface conditions are of paramount importance. Minute traces of chemically active gases produce surface films which can modify the contact potential markedly. It is therefore not surprising that many discrepancies among the results of various investigators arose in the early work which did not utilize vacuum techniques. Even under the most carefully controlled conditions, reproducible results have not always been obtained.

Considerable confusion has arisen in the literature as a consequence of the many definitions adopted by different authors. For example, terms such as "contact potential," "Volta potential," "contact potential of the first kind," "contact potential of the second kind," "inner" or "outer Volta potential," etc., occur in various references. All of the aforementioned terms have been applied to the potential difference which exists at the point of contact of two metals. Furthermore, this terminology has been employed in the discussion of the contact potential between various pairs of the classes of solids defined by the nature of their electrical conductivity as ionic conductors, electronic conductors, or dielectrics. For example, Gysae and Wagener (5) defined four varieties as follows:

(1) Electronic conductor–electronic conductor: "Galvani potential."
(2) Electronic conductor–dielectric (vacuum between bodies): "Contact potential" when bodies are electrically connected; "charge potential" when bodies are insulated.
(3) Electronic conductor–ionic conductor: "Volta potential."

However, the most prevalent practice has been to denote the quantity measured by the various methods which will be described later as the *contact potential* or *Volta potential*.

The term "Galvani potential" has in general been relegated to the electrochemical phenomenon as distinguished from this purely physical effect. It symbolizes the supposed electrical potential *inside* a phase, and unfortunately, is an indefinite quantity. This so-called "internal potential" is the sum of the electrostatic potential outside a phase, and the electrostatic part of the work required to take electrons from the interior through the transition layer at the surface, to the point outside at which the electrostatic potential is measured. There are no known means of distinguishing between the electrostatic part of the work of extraction of an electron and the chemical part due to the difference in chemical environment of the electrons in the interior of the phase and outside.

II. THEORY OF CONTACT POTENTIAL

A. *Fundamental Principles*

The theory of electrical conductivity leads to the conclusion independently of experimental evidence that a potential difference should

exist between the interiors of two metals in contact even when their temperatures are equal. In the equilibrium state this is represented by the equation:

$$V_2 - V_1 = \frac{(\zeta_2 - \zeta_1)}{e}, \tag{1}$$

where ζ is the Gibbsian thermodynamic potential of the electrons, designated as the Fermi energy at temperature T, and e is the electronic charge. The derivation of this fundamental relationship will be outlined later.

The quantity $(V_2 - V_1)$ cannot be measured, however, owing to the fact that its magnitude depends upon the zero-point energies in the two metals. For free electrons, these energies may be regarded as equal to zero when the kinetic energies are zero. In this case ζ_1 and ζ_2 represent purely kinetic energies, and the internal field shifts the energy zero by an amount $(\zeta_2 - \zeta_1)$ such that:

$$(\zeta_1 - eV_1) = (\zeta_2 - eV_2). \tag{2}$$

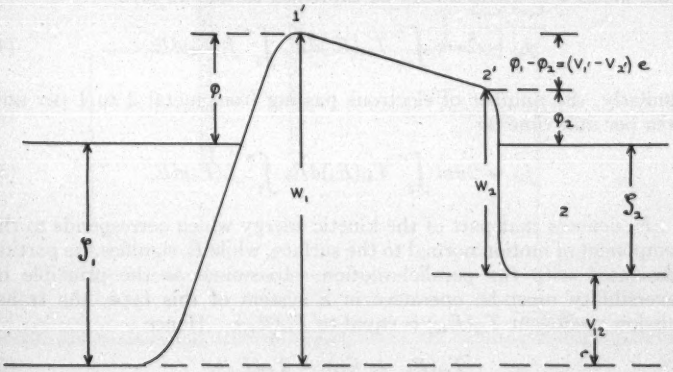

FIG. 1.

Although the internal field is not measurable, the contact potential, that is, the difference in potential between two points just outside each metal, is independent of the zero-point energies, and hence measurable. The situation is indicated in Fig. 1. Here $-W_1$ and $-W_2$ are the potential energies of an electron in the specified metal relative to a vacuum, whereas φ_1 and φ_2 represent the respective work functions. The potential difference between points 1′ and 2′, or the contact potential, is given by:

$$V_{2'} - V_{1'} = \frac{1}{e}[(W_1 - \zeta_1) - (W_2 - \zeta_2)] = -\frac{(\varphi_2 - \varphi_1)}{e}. \tag{3}$$

B. Derivation Based Upon Free Electron Model

According to the usual connotation, a contact is described as a junction at which the distance apart between the bodies is comparable, at least in order of magnitude, with inter-atomic dimensions. It is entirely consistent with wave-mechanical principles for electrons to pass even across a relatively large gap at any temperature including absolute zero. The wave function will undergo total reflection at the surface of the first metal, but it is possible for penetration to occur into the second metal, with the amplitude of the transmitted wave decreasing exponentially.

It is evident that, in accordance with the above definition, two surfaces are in actual contact over a very limited region, and the major portions are separated by gaps many atomic dimensions wide. Of course, these gaps must be taken into account in any theory of the conduction of electricity.

Consider two metals as indicated in Fig. 1. Here, an exchange of electrons between 1 and 2 will occur. The current density j_{12} flowing from metal 1 to metal 2 may be expressed as follows (6):

$$j_{12} = 2\pi m \int_0^\infty T_{12}(E_x)dE_x \int_0^\infty f_1(E_1)dE_r; \tag{4}$$

similarly, the number of electrons passing from metal 2 to 1 per unit area per unit time is:

$$j_{21} = 2\pi m \int_0^\infty T_{21}(E_x)dE_x \int_0^\infty f_2(E_2)dE_r. \tag{5}$$

E_x denotes that part of the kinetic energy which corresponds to the component of motion normal to the surface, while E_r signifies the portion associated with the parallel motion. Inasmuch as the principle or reversibility must be operative in a system of this type, the transmission coefficient $T_{21}(E_{x_2})$ is equal to $T_{12}(E_{x_1})$. Hence

$$T_{21}(E_{x_1} + V_{12}) = T_{12}(E_{x_1}), \tag{6}$$

where V_{12} denotes $(E_{x_2} - E_{x_1})$, that is, the decrease in potential of an electron passing from metal 1 to 2.

From the above relationships:

$$j_{21} = 2\pi m \int_0^\infty T_{12}(E_x)dE_x \int_0^\infty f_2(E_1 + V_{12})dE_r. \tag{7}$$

Hence the net flow in the direction $1 \rightarrow 2$ per unit area per unit time is given by:

$$J = \frac{2\pi m}{h^3} \int_0^\infty T_{12}(E_{x_1})dE_x \int_0^\infty [f_1(E_1) - f_2(E_1 + V_{12})]dE_r. \tag{8}$$

For equilibrium, J must vanish. This can occur only if in the latter equation:

$$f_1(E_1) = f_2(E_1 + V_{12}) = f_2(E_2). \tag{9}$$

Since

$$f_1(E_1) = \frac{2}{h^3\epsilon^{\frac{(E_1 - \zeta_1)}{kT}} + 1} \tag{10}$$

it is seen that, provided the two metals are at the same temperature, this condition can be fulfilled if:

$$E_1 - \zeta_1 = E_2 - \zeta_2 \tag{11a}$$

or

$$V_{12} = E_2 - E_1 = \zeta_2 - \zeta_1. \tag{11b}$$

This fundamental result was stated earlier in this section as Eq. 1.

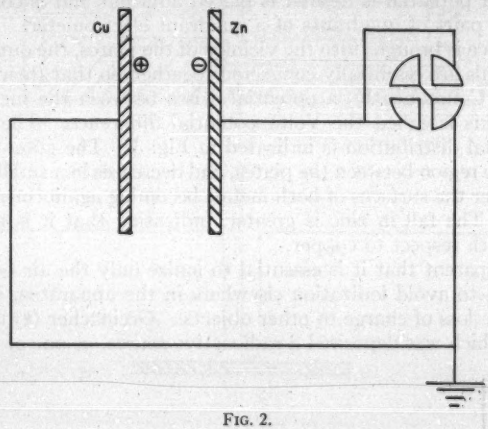

FIG. 2.

III. METHODS FOR MEASURING CONTACT POTENTIALS

A large variety of methods has been employed for investigating this phenomenon. As is generally true in the case of effects which are dependent upon the surface conditions of the material under investigation, the results have often not been reproducible. In some instances, on the other hand, measurements conducted by different methods have yielded excellent agreement.

A. Ionization Method

The original experiments performed by Kelvin (7) utilized a technique which is exceedingly simple in principle. The method is repre-

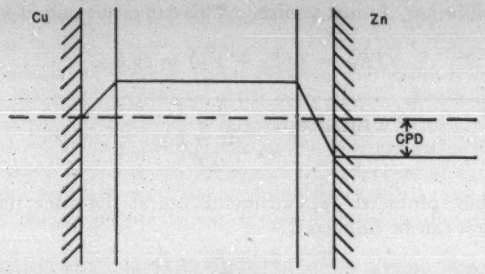

FIG. 3.

sented schematically in Fig. 2. One of the metals, copper in the example, is grounded, whereas the other metal with respect to which the contact potential is desired is placed adjacent and is connected to one of the pairs of quadrants of a quadrant electrometer. If a radioactive source is brought into the vicinity of the plates, the outer surfaces of the metals are essentially connected together, so that their potentials equalize. Consequently, a potential arises between the metals themselves. This is called the Volta potential difference. The nature of the potential distribution is indicated in Fig. 3. The potential is constant in the region between the plates, and decreases in a small transition region under the surfaces of both metals becoming again constant in the interiors. The fall in zinc is greater, indicating that it is negatively-charged with respect to copper.

It is apparent that it is essential to ionize only the air between the plates, and to avoid ionization elsewhere in the apparatus, in order to prevent the loss of charge to other objects. Greinacher (8) used a lead strip, on which was deposited a radioactive source, as one of the plates.

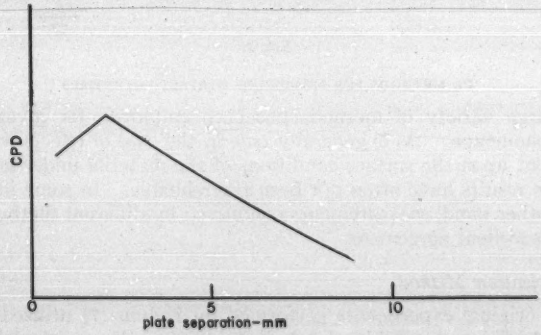

FIG. 4.

This permitted bringing the metals very close together and thereby reducing the irradiation of the surroundings. However, this does not completely solve the difficulty. Owing to the short range of the alpha particles, the magnitude of the electrometer deflection depends upon the separation of the plates. In order to utilize completely the ionizing potentialities of the source, the radiation proceeding from it should traverse a certain optimum thickness of air. Upon increasing the separation of the plates, the effect of recombination of ions enters, causing a subsequent decrease. As a consequence, a curve such as that shown in Fig. 4 is obtained. It was observed that the best separation is approximately 2 mm., for the tellurium source used. As a control upon the experiment, Greinacher also observed the resistance of the

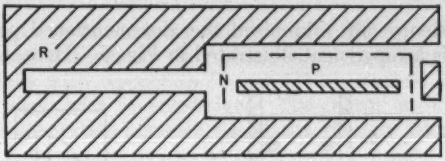

FIG. 5.

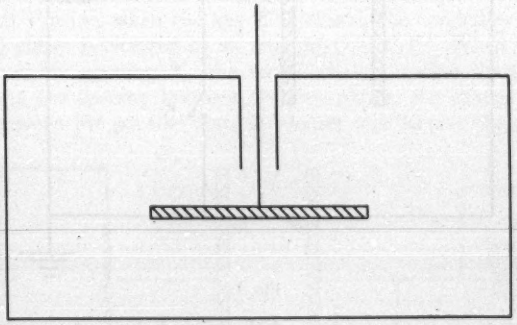

FIG. 6.

cell, to determine whether water droplets or other disturbances were operative.

K. T. Compton (9) improved the apparatus by using as one metal a wire net *N*, and as the other a plate *P* in a large lead container. The radium source was then situated at *R*. This device had the advantage that photoelectric measurements could also be conducted at the same time. Radiation of the surrounding region is here practically entirely avoided. The arrangement is illustrated in Fig. 5. In principle, the use of a third metal as a tank is not free from objections, inasmuch as

the potential difference of the metal under investigation with respect to lead might introduce errors. However, in practice, this does not appear to be significant. The values of the Volta potential thus determined seem to agree quite well with those obtained from photoelectric measurements, as may be concluded from the summary of Compton's results in Table I.

TABLE I.—*Comparison of Contact Potential Difference of Various Metals with Respect to Cu, as Determined by the Ionization and Photoelectric Methods (Ref. 9)*

	Al	Zn	Pb	Fe	Pt
Ionization Method	1.02	0.75	0.55	0.15	−0.11
Photoelectric Method	1.16	0.70	0.50	0.25	−0.14

J. J. McHenry (10) minimized the aforementioned possible source of error in his arrangement illustrated in Fig. 6. Here, the metal box

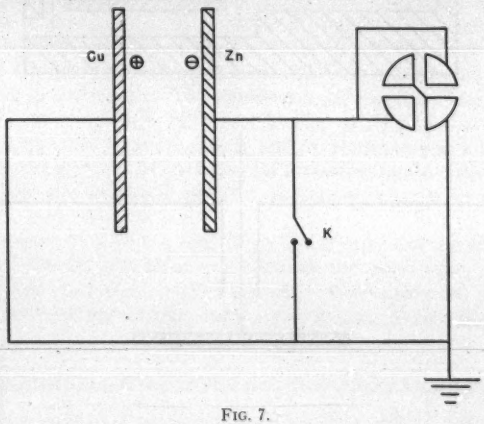

FIG. 7.

itself served as one electrode, and the second electrode was introduced through a very narrow orifice.

B. Condenser Method

The arrangement originally employed by Kohlrausch (11) but usually designated as the Kelvin method, here is indicated schematically in Fig. 7. If the key *K* is closed, the metals themselves are connected rather than the surfaces of the metals as in the previous method. The potential distribution is then represented by Fig. 8. The potential now has the same height in both metals. In the transition regions, there is an increase which differs for the two metals, and consequently a drop

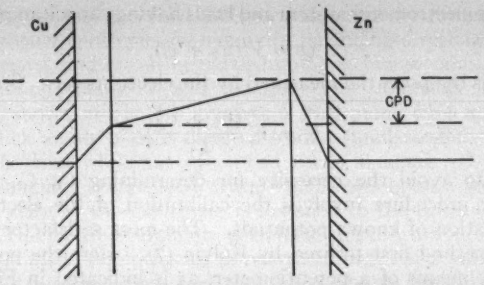

FIG. 8.

in potential occurs in the space between the surfaces. The electric field in the interspace is exactly that which would be produced by charging zinc positively with respect to copper. This method ostensibly leads to a Volta effect with reversed sign. The charge is then measured by varying the separation between the plates, thereby altering the capacitance. The measurement can be performed in various ways, although a null method is most satisfactory.

As a consequence of the fact that, in the arrangement of Fig. 7, a potential V arises when the key K is closed, the condenser comprising the two plates is charged to an amount $Q = C_1V$. When the Zn side is isolated by opening K, the entire charge resides thereon. Upon increasing the spacing between the two plates, the charge distributes itself between the parallel plate condenser now having the capacitance

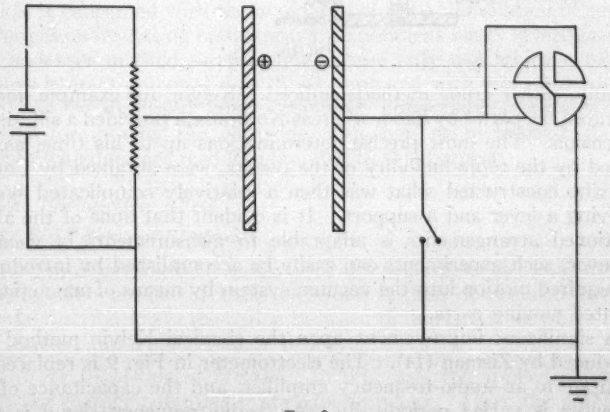

FIG. 9.

C_2, and the electrometer system and leads having capacitance C. Hence:

$$Q = V'(C_2 + C), \tag{12}$$

where V' is the potential measured by the electrometer. Consequently:

$$V = V' \frac{(C_2 + C)}{C_1}. \tag{13}$$

In order to avoid the necessity for determining C_1, C_2, and C, the customary procedure involves the calibration of the electrometer by the application of known potentials. The most satisfactory procedure is a null method first utilized by Kelvin (7). Here the potential P is applied by means of a potentiometer, as is indicated in Fig. 9. This method is rather time-consuming, and even modifications such as the plotting of deflection *vs.* bucking potentials proposed by Ende (12) are relatively cumbersome.

The principal problem associated with the condenser method is the necessity for providing a mechanism for altering the plate separation.

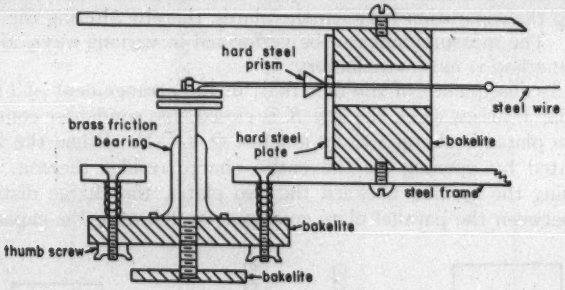

FIG. 10.

Initially, rather crude methods sufficed. Kelvin, for example, merely separated the plates by hand, whereas Kohlrausch provided a silk thread suspension. The most precise determinations up to his time, as evidenced by the reproducibility of the results, were obtained by Conrad (13) who constructed what was then a relatively complicated system involving a lever and a support. It is evident that none of the aforementioned arrangements is adaptable to measurements in vacuum. However, such experiments can easily be accomplished by introducing the required motion into the vacuum system by means of magnetically-actuated moving parts.

A significant improvement upon the classical Kelvin method was introduced by Zisman (14). The electrometer in Fig. 9 is replaced by the input to an audio-frequency amplifier, and the capacitance of the condenser is varied periodically. An audio-frequency signal is then

heard until the applied potential difference balances the contact potential. The measurement consists merely in balancing a resistance until no signal is heard, and it can be carried out in a few seconds, whereas the older method was slow and tedious. The vibrating condenser arrangement, shown in Fig. 10, involves a steel piano wire against the middle of which an air blast is directed from a small nozzle. One end of the wire is fixed while the other end rocks a metal rod threaded through a triangular knife-edged prism which rests upon a steel plate. The moving plate of the condenser is fastened to the other extremity of the rod. The method originally permitted the measurement of contact potentials with certainties up to one-thousandth of a volt in but a few seconds of manipulation, and this can probably be improved by modification of the amplifier.

This principle would be very valuable for studies of variations with orientation of the contact potential between the faces of single metal crystals and some standard metal surface, or in the study of rapid changes with time of the contact potential between pairs of newly prepared surfaces. Furthermore, information regarding the uniformity of the metallic surface is provided by the fact that a zero sound minimum is obtained only with a uniform surface. In a modification developed by Rosenfeld and Hoskins (15) the condenser plate was vibrated by 60-cycle current.

The condenser method has many advantages, certainly as compared with the ionization method which has the fundamental disadvantage that the measurements depend upon the resistance of the ionized air. Obviously the condenser method can be utilized in vacuum, and furthermore the sensitivity is considerably higher. The principal precaution, aside from the usual requirements regarding vacuum and degassing practice, is concerned with the avoidance of the accumulation of spurious charges on insulating bodies near the specimens under investigation. The condenser method, in principle, is the only one which actually measures contact potential directly as compared with other procedures which will be discussed later. Its most unfavorable aspect is the necessity for moving the electrode, although, as mentioned above, modern techniques are readily adaptable to this purpose.

C. The Photoelectric Effect

1. Field Between Electrodes

The photoelectric effect merely provides a source of electrons in this instance. The motion of these electrons is then determined by the potential distribution in the region between the surface from which they were emitted and a second metal nearby.

(*a*) *Curve Displacement Method.* In this case, the applied potential P and the contact potential V are superimposed. Thus, the potential between the electrodes is given by $V_1 = P + V$ with a given anode,

and $V_1' = P + V'$ with another anode. It is evident that with the same applied voltage, the effective potential differs for different metals. Consequently, as may be seen in Fig. 11, a parallel displacement of the *photocurrent vs. applied potential* curve results. Inasmuch as zinc is positive with respect to copper, the curve obtained with the former material appears on the left.

K. T. Compton (9), utilizing a plate cathode surrounded by a grid anode, measured contact potentials by both the ionization method and by this method, and obtained the results listed in Table I.

(*b*) *Saturation Current Method.* The difficulties associated with the procedure described above are circumvented in the saturation current method. Here the cathode is surrounded by an anode and conditions are established such that no field exists in the interspace. Electrons leave the cathode with all possible velocities between zero and a certain

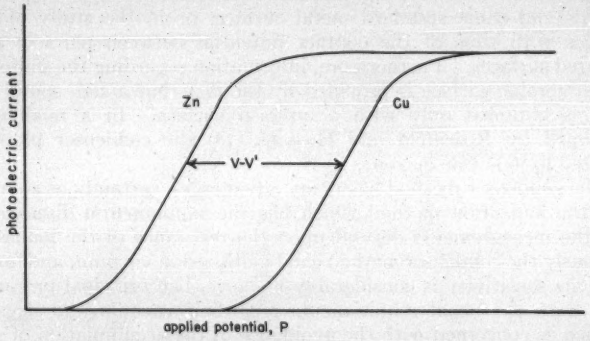

FIG. 11.

maximum. However, the precise velocity distribution plays no role, inasmuch as all electrons emanating from the cathode with finite velocity must reach the anode owing to the absence of an interelectrode field. Consequently the photoelectric current must first exhibit a saturation value when the true potential becomes equal to zero. As the potential between the electrodes decreases from cathode to anode, some of the electrons are repelled. The actual potential is equal to zero only when the applied potential is equal to the contact potential, and it is evident that, in principle, the contact potential corresponds directly to the value of applied voltage at which saturation current occurs.

Measurements of this type (16, 17, 18, 19) are usually performed in a glass envelope having an evaporated metallic layer, for example, silver, which serves as anode. The cathode may be in the form of a foil or another evaporated layer located as near the center of the anode as possible. Light is admitted through a port in the anode, and an opening

must be provided for introducing the specimen. Owing to the latter factors, the vessel is not completely closed, hence a rounding of the saturation curve rather than a sharp break is observed in practice. Extrapolation is required for determining the voltage at which saturation occurs, as may be seen in Fig. 12. Teichmann (20) reports agreement between measurements obtained with this method and with the condenser method.

Inasmuch as measurements of the magnitude of the saturation current are obtained in this procedure, some control is maintained over the state of degassing of the surface.

(*c*) *The Photoelectric Yield.* It has been shown (21) that the Voltaic series corresponds with the arrangement of metals according to their photoelectric yield. However, quantitative determinations of the latter

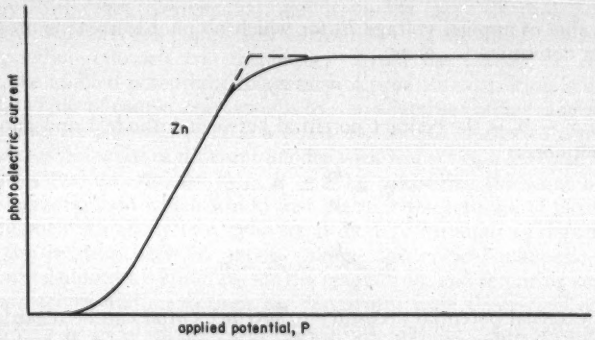

FIG. 12.

factor require knowledge of the photocurrent, the surface area, the light intensity and spectral distribution, the absorption in quartz windows, etc. The latter two characteristics are difficult even to hold constant, and so this method does not seem very practicable as a means of determining the contact potential.

2. Work Function

(*a*) *Long Wave Length Limit.* The well-known photoelectric equation of Einstein is:

$$V = \frac{h\nu}{e} - \varphi. \tag{14}$$

V represents the value of applied potential such that no photoelectrons are emitted. When $V = 0$, $\nu = \nu_0$ and $\varphi = \frac{H\nu_0}{e}$. It is thus assumed that V can be determined precisely. Presumably, in accordance with

Eq. 3, the contact potential could be obtained directly from a comparison of the work functions as determined in this manner. However, in practice, the situation is not so clean-cut. Actually, it is found that φ can be represented as the sum of two terms p and q, of which the former relates to the contact potential, and the latter represents a remainder. Although according to experimental indications q has the same value for all metals, the explanation for its existence is not well understood. The empirical approach makes use of the following relationships:

$$V_1 = \frac{h\nu}{e} - p_1 - q_1 \tag{15a}$$

$$V_2 = \frac{h\nu}{e} - p_2 - q_2. \tag{15b}$$

The value of applied voltage P_1 for which no photocurrent is observed is then determined. Now:

$$V_1 = P_1 - (p_1 - p_0), \tag{16}$$

where $p_1 - p_0$ is the contact potential between cathode 1 and anode 0. Furthermore:

$$q_1 = \frac{h\nu}{e} - P_1 - p_0 \tag{17a}$$

and

$$q_2 = \frac{h\nu}{e} - P_2 - p_0. \tag{17b}$$

If the external potential necessary to produce cutoff can be regarded as constant for different cathodes and the same anode, $P_1 = P_2$ and hence $q_1 = q_2$. However, the general ignorance regarding the physical identification of q makes this method very unsatisfactory.

The measurement of the long-wavelength limit is accurate only to within several per cent. Inasmuch as values of the work function usually range between 2–6 volts, the inaccuracies amount to some tenths of a volt, which is of the order of magnitude of the Volta effect. In view of the fact that two such values are required for the determination of contact potential, the limitations of the method are apparent.

Representative values obtained by Richardson and Compton (17) using both the saturation-current method and photoelectric threshold determinations are given in Table II.

TABLE II.—*Comparison of Contact Potential Measurements, in Volts, Obtained with Respect to Platinum by Two Different Methods (Ref. 17)*

	Cu	Bi	Sn	Zn	Mg	Al	Na
Saturation-current Method	0.13	0.35	0.62	0.90	1.05	1.2	2.4
Long Wavelength Limit	0.30	0.64	0.64	0.85	1.00	1.31	2.2

D. Thermionic Emission Methods

These methods are similar to the photoelectric measurements in that one metal of a pair under investigation emits electrons, in this instance thermionically. The principal advantage is that the materials under investigation may be carefully degassed under vacuum conditions, particularly if the specimens are fabricated in the form of wire filaments.

1. *Field Between the Electrodes*

The remarks in Section III-*C* are equally applicable here, inasmuch as the mode of production of the electrons is not a pertinent factor. The method involves the observation of the displacement of the characteristic *current vs. voltage* curve of a vacuum tube.

(*a*) *Diode Method.* The saturation-current method was originally used by Rothe (22), Germer (23), and Reynolds (24). In their experiments, a filament was completely surrounded by the anode, as in the corresponding photoelectric technique. From the *current vs. voltage* curve, the applied potential P necessary to produce saturation is determined. This, of course, corresponds to zero effective voltage, and hence to the contact potential. It is a relatively simple matter to compare the contact potential of different anodes with respect to a fixed cathode.

Oatley (25) determined $V_1 = V + P$ by measuring the value of the axial magnetic field which would just prevent the passage of electrons from filament to anode in a cylindrical diode. An analysis depending upon the relation between anode voltage and critical magnetic field originally deduced by Hull (26) for the magnetron, and requiring several approximations and corrections for departures from theoretical conditions owing to the absence of a sharp cutoff, permits the calculation of the desired quantity from the experimental data. The error of the determinations thus made is ± 0.02 volts.

The curve-shift method is superior to any of the aforementioned. In various forms, it was initially used independently and simultaneously by Mönch (27), Langmuir and Kingdon (28), and Patai (29, 30, 31, 32). The simplest arrangement utilizes a filament and a plate, the latter being replaceable by another specimen. The *current vs. voltage* curves

TABLE III.—*Comparison of Contact Potential Difference Between Cu and Ni, as Measured Successively by the Condenser and Saturation-Current Methods (Ref. 27)*

Volts	Method
0.26	Condenser
0.20	Saturation-current
0.22	Condenser
0.24	Saturation-current
0.22	Condenser
0.22	Saturation-current

corresponding to the various anodes are then plotted, and the parallel shift corresponds to the contact potential between the two anodes. Mönch has compared this method with the condenser method and, as may be seen in Table III, a series of measurements alternately performed on a given specimen are in good agreement.

(*b*) *Triode Method.* The three-electrode tube may be utilized in several ways. One technique involves the measurement of the contact potential between the grid and anode, with the filament serving merely as a source of electrons. It is necessary to provide for the control of effects such as a potential drop across the filament, and the temperature of the filament. As is indicated in Fig. 13, the grid is connected directly to the cathode, and the variable voltage P is applied between the grid and the anode. The shift in the V–I curve is then observed. Either the grid or the anode may be changed, and the electrodes may be in the form of plates or cylinders.

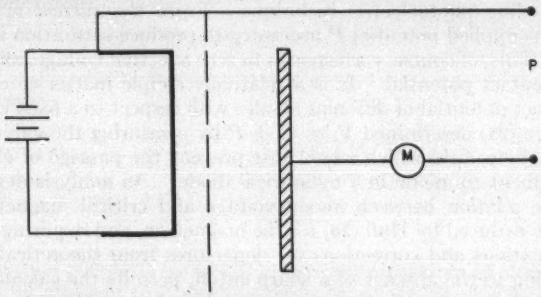

FIG. 13.

The most advantageous method for many applications is that originated by one of the authors (**29, 30, 31, 32**). No mechanical system is required for introducing motion into the vacuum tube. Careful degassing of the specimens can be accomplished, and sources of error arising from inhomogeneous field distributions are minimized by the concentric electrode arrangement without the introduction of guard electrodes.

The procedure consists of the determination of the characteristic curve of a three-electrode tube. This is measured first with a grid of the metal under investigation, and then again after a uniform layer of another metal has been coated thereon. In the first case, the characteristic curve is governed by the contact potential difference between the filament and the base metal of the grid, and in the second by that between the unchanged filament and the coated grid. The difference between the two cases manifests itself as a parallel shift of the characteristic curve, and the amount of the displacement constitutes a measure

of the contact potential between the grid base metal and the evaporated metal layer.

The shift is to the left, that is, toward negative values of grid voltage, if the grid is covered in the second instance with a metal for which the work function is smaller than for the base metal. In all of the experiments utilizing this method, sodium was employed as the covering applied to various bases to serve as a reference metal. In the first place, this metal can be introduced into an evacuated tube in a very pure state, by a method developed by one of the writers (33). Secondly, inasmuch as the work function for sodium is considerably smaller than that for the grid materials, an observable effect is always produced. Finally, the reference layer of sodium can easily be evaporated by heating the grid. Thus, the reproducibility of the measurements may

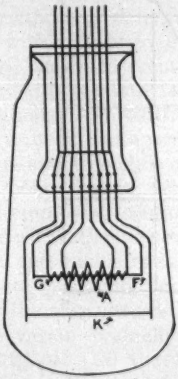

FIG. 14.

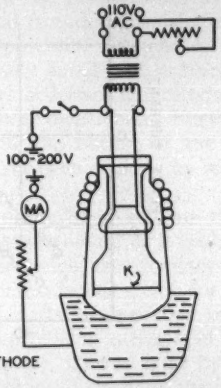

FIG. 15.

readily be checked by alternately glowing the spiral grid while the envelope is cooled, taking data, and then repeating after the glass envelope has been heated to recoat the grid. Figure 14 indicates the construction of the experimental tube. The grid G, as well as the spiral anode A of the triode, has two leads to permit heating directly by electric current. An auxiliary cathode K serves as the source of electrons for the electrolytic introduction of sodium into the tube. The envelope is constructed of soft lead-free glass. Usual vacuum precautions and procedures are observed in the preparation of the tube which is finally sealed off under conditions such that the residual pressure is less than 10^{-8} mm. of Hg.

Sodium is introduced into the tube by an electrolytic process which is represented in Fig. 15. Any sodium salt may be used, although

$NaNO_3$ has the advantage of a low melting point. The bottom of the experimental tube is immersed in the molten salt, while the upper portion is surrounded by a cooling coil. A potential of the order of 100 to 200 volts is applied between the auxiliary cathode *K* and the salt. Currents of about 5 to 15 milliamperes flow during the process, and after 4 to 5 minutes the cooled walls of the tube become coated with a metallic mirror-like layer of sodium.

The characteristic curve (plate current *vs.* grid voltage) of the triode prepared in this manner is then obtained with at least two different

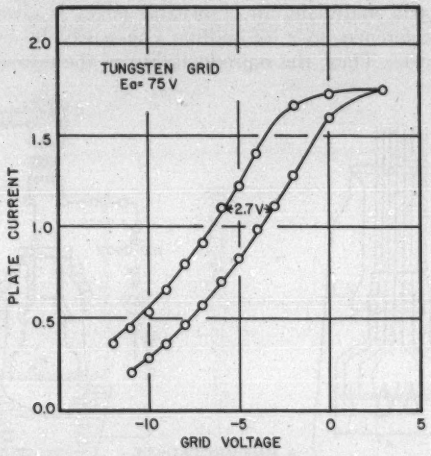

FIG. 16.

anode voltages. The shift of the characteristic curve corresponding to the clean grid with and without the sodium layer turns out to be completely independent of the anode voltage. The curves of Fig. 16 are typical of those obtained with this arrangement. The results of measurements on various materials are summarized in Table IV. The

TABLE IV.—*Measured Values of Contact Potential Differences of Various Metals with Respect to Na (Ref. 31)*

Mo	W	Fe	Ni	Pt	Cu
2.0	2.7	1.4	2.45	2.1	2.05

contact potential differences with respect to sodium are in good agreement with values deduced from the differences of work functions determined thermionically and photoelectrically in the case of the particular metals investigated.

2. *Work Function*

The theoretical discussion in Section II leads to the conclusion that the contact potential between two metals is equal to the difference between their work functions. This would suggest that the measurement of work functions should provide a satisfactory method for evaluating contact potentials. However, the difficulties associated with accurate work function determinations are well known, and the limitations mentioned in the discussion of photoelectric measurements are equally applicable here.

IV. CONCLUDING REMARKS

It has not been the purpose of the present paper to provide an extensive survey of the entire subject of contact potentials. On the contrary, attention has been confined to the fundamental aspects of this subject, and particularly to a critical consideration of the experimental methods of determining contact potential differences. In conformity with this point of view, extremely small temperature effects which are known to occur, but which are orders of magnitude smaller than contact potentials (**34**, **35**) have not been mentioned. Furthermore, the additional complications inherent in the nature of the contact between a metal and a semi-conductor have been avoided by restricting the discussions to metals only.

This policy has its inception in the desire to investigate the feasibility of employing contact potential measurements as a tool, in conjunction with other types of observations such as secondary-electron emission, thermionic emission, and the photoelectric effect, for arriving at a more profound understanding of certain properties of solids. Perhaps the most interesting theoretical problems in this field relate to the observation originally made by Rose (**36**, **37**) and later by Kurzke and Rottgardt (**38**) that the contact potential depends upon crystal orientation in the case of single crystals.

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NOTES FROM THE NATIONAL BUREAU OF STANDARDS

FIFTIETH ANNIVERSARY OF THE NATIONAL BUREAU OF STANDARDS

In Philadelphia on September 10, 1884—the third day of the United States Electrical Conference, held in conjunction with the International Electrical Exhibition sponsored by The Franklin Institute—Professor Monroe B. Snyder, a prominent member of The Franklin Institute and Secretary of the United States Electrical Commission, opened a discussion on "The Establishment of a National Bureau of Physical Standards."

Since that occasion, to the best of our knowledge, marks the beginning of the efforts to establish a National Bureau of Standards in this country, the editors of the JOURNAL feel that it would be of interest to reprint Mr. Snyder's remarks, in honor of the Bureau's fiftieth anniversary this year. It is interesting to note that, while the establishment of the Bureau was advocated in 1884 at The Franklin Institute, the Bureau was not founded until 1901.

ADDRESS OF PROFESSOR SNYDER

MR. PRESIDENT AND GENTLEMEN:

The establishment of a Bureau of Standards adequate to the scientific and practical needs of the nation is a topic that may well claim the attention of the public at any time. There are, however, several reasons for bringing the question before this National Conference of Electricians.

The International Commission having recently determined what the international electrical standards are to be, it remains for this country to give proper and official attention to the important matter of recognizing and establishing such standards.

And again, it is found, at the very outset of a movement in this direction, that the definition and construction of the electrical standards necessarily involves the definition and construction of a number of other physical standards; since to attempt the establishment of a standard of resistance, for example, without reference to standards of temperature, length, or even of mass, would be to fail in the first statement.

But more than all, with the presence at this Conference; of physicists, of practical experts, of manufacturers and others interested, we may expect that this matter will receive the many-sided consideration which its importance deserves.

It may be well at the outset to glance briefly at the present condition of the subject of physical standards in this country. Standards of length and of mass have long since received considerable attention from a department of the United States Coast Survey. This Bureau is, I believe, sometimes designated as the Bureau of Weights and Measures, and furnishes standards of this class to the several States.

The original intention of attaching such a Bureau to the Coast Survey was undoubtedly to provide proper standards for its important geodetic work, and in pursuance of this intention the Bureau has undoubtedly been useful.

We find, however, at a later period the department of the Lake Survey independently taking up the subject of the standards of length in a very spirited manner and with a success creditable to those engaged in the work. It is also understood that the Coast Survey itself has recently been active in some improvements in this department.

As for the other standards connected with Government operations we have notably the attempts of the Signal Office to determine for their work standards of pressure and of temperature, and we are also informed that in some of the Government work preliminary electrical standards have been adopted, though doubt has been expressed as to whether the same standard is used throughout the entire service, and, as a matter of course, is still more doubtful whether these standards harmonize with the present state of electrical science.

It will be noted that all these attempts on the part of Government officials to establish physical standards, creditable as they may be in themselves, have been mainly with the view of meeting the necessities of their own particular departments, but are scarcely available for the scientist and the practical public.

Outside of the Government Departments private enterprise has, indeed, done much to further the study of this subject, and in several educational centers most laudable efforts have been made to establish and reproduce standards of length and of temperature. Thousands of dollars have been expended by individuals and institutions in this direction, and yet with all deference to, and recognition of, this self-denial and enterprise, it can scarcely be supposed that the private purse will be equal to the support of the amount and the character of work that yet remains to be done in this direction. While, therefore, too much cannot be said in praise of these individual attempts, whether undertaken in the Government service or by private effort, to lay a firm foundation for our science and our practice, there still remains the necessity for the establishment of a National Bureau of Physical Standards that shall at once unify all the standards of the various Governmental Departments, and also be equal to the real wants of progressive science and actual practice in this country.

It is perhaps important that we indicate in brief and in outline the character of the Bureau intended.

It should, in the first place, aim to determine and reproduce all the physical standards with relation to each other. In the present state of science it is so manifestly absurd to determine or even to state one standard without respect to the others, that it does not seem necessary to emphasize this point. Still we may, in passing remind ourselves of the fact that, as the matter now stands, one must often be in serious doubt as to precisely what subsidiary standards were used in work where observations are not made at a physical zero. Such Bureau would then provide for standards of length, of mass, time, temperature, of electrical resistance and electro-motive force, of light, and also probably provide for other subsidiary standards necessary to the great business interests of the country. In the second place, the proposed Bureau should not only be broad in scope, but should thoroughly provide for two distinct and yet related features.

First, the standards should be the embodiment of all the scientific research at present available in these matters. Some plan should, therefore, if possible, be devised to eliminate the personal equation which, even in matters of high scientific research, becomes at times unfortunately too prominent. There seems, indeed, no good reason why such a Bureau should not avail itself of all the experience and research in these matters that can be supplied by the trained physicists of this country.

Then, again, methods and means should be provided for furnishing the public with authoritative multiples and submultiples of such standards.

This means not only that research should be undertaken for determining the best methods of copying, multiplying, and subdividing standards, but that means should be provided by which the public can readily obtain such copies, multiples, and submultiples. It should not be difficult for any one, whether engaged in scientific or practical pursuits, to obtain standards of an accuracy equal to the purpose for which they are desired.

It seems, moreover, necessary to the effectiveness of such a Bureau that it should have the stamp of Government sanction and of Government support.

Excellent from a scientific standpoint as some of the standards championed by individuals and institutions may be, there is yet wanting the stamp of authority to make these researches definitely valuable to the community.

On the other hand, the standards determined by Government departments have indeed the

advantage of quasi-governmental authority, but are, as previously stated, in such a shape as not to be either strictly related to each other or practically accessible to the public.

The character of the Bureau here intended should be also defined as incompatible with any present department of the Government service. It cannot be supposed that a Bureau of Physical Standards of the character and scope here intended could be either scientifically or practically supported by any one of the present departments of the Government service. It should, therefore, in our opinion, both on account of the practical and scientific interests at stake, be both in its constitution and in its business and scientific management a department of its own.

In order to complete a Bureau of the character described it would also be necessary to have associated with it a physical laboratory and observatory of no mean pretensions, a laboratory devoted exclusively to researches connected with such work, an observatory that would carefully note the physical conditions under which the standards are preserved, and also, if possible, serve as a central station at which physical observations, to be made by the various departments of the Government service and by private individuals, may be compared and to which they may be reduced.

In short, we may say that this Bureau of Standards should occupy, with respect to the practical physics of the country, precisely the same relation that the Nautical Almanac Office holds with respect to practical astronomy.

And just as formerly Government aid was invoked and is now freely furnished for the observation and computation of data which form the basis of the actual work in the astronomical observatory and of the plain sailing of the mariner, just as Government aid has enabled the accumulation of data of every-day importance to the astronomer, the geographer, and the sailor, just so should Government aid now be invoked to furnish a Bureau for the determination, the subdivision, the preservation, and the development of a series of physical standards which shall be adequate to the urgent needs of the physicist, and also be available for the practical expert and the manufacturer.

This address by Professor Snyder was reprinted for the 56th Congress in 1900, establishing the Bureau. The Franklin Institute is honored to have contributed in this way to the founding of the National Bureau of Standards.

MUSEUM

We all use the expression, "As simple as A. B. C." But few of us ever give a thought to the origin of the alphabet. It cannot have been so simple as the common expression would imply. The first methods used by primitive man in conveying his ideas and recording events were crude pictographs cut in stone, or scrawled on bark or leaves. These were the forerunners of the alphabet which only began to take form with the Phoenicians about three thousand years ago. Their alphabet comprised twenty-two forms, really immature and simplified pictures of familiar things. The Greeks, in their commercial relations with the Phoenicians, realized the importance of their alphabetic writing and adopted it about 800 B.C. They appropriated fifteen of the Phoenician letters and added nine of their own to make an alphabet that fitted their needs. Later, the Romans borrowed their letter forms from the Greeks. Their alphabet reached its full development approximately two thousand years ago. The letters G, J, U, and W were added at a later date but substantially the Roman alphabet we use today is the same as that in use at the beginning of the Christian era.

Why is the letter A the first letter of the alphabet? Because it was natural the Phoenicians would select something of importance to man to lead all the rest of their letters. They chose food, represented by the head and horns of the ox. If you will glance at the Phoenician alphabet illustrated in the Graphic Arts section of the Museum, it will be seen that the first letter is represented by two crude strokes drawn diagonally with the apex at the bottom and crossed about midway by a horizontal bar. Through constant repetition and the need for speed, the character was eventually made with one stroke, the horizontal bar being drawn as a diagonal line. Some seven centuries before the Christian era the Greeks introduced symmetry and balance into the letter when they adopted it with some others. Seven centuries later the Romans made the change which has persisted to this day when they made the diagonal into a horizontal bar.

The second letter of the alphabet is also indicative of something of unusual significance to man, his shelter. The Phoenician character was a crude symbol representing a house, which they called Beth (Bethel, the house of God; Bethlehem, the house of bread). Written at speed by the Greeks this became corrupted into two triangles on end, one above the other. The Romans curved the angular parts, as was their practice in altering a number of Greek letters, and gave us the letter B we use today.

The third letter employed by the Phoenicians symbolizes their great feats in transportation. The inspiration was the head and long sloping neck of a camel. The Greeks merely eliminated the curves in the character, which were more amply restored by the Romans to form the letter C.

And so the story might be carried on, but the reader is recommended to examine the series of ancient alphabets displayed in the Hall of Graphic Arts and trace for himself the fascinating development of our alphabet. It should be borne in mind that the tools employed by the scribes had much to do with the formation of the letters. Chinese ideographs display the influence of the brush; Babylonian cuneiform writing done in clay shows evidence of the use of an angular tool; Greek manuscripts exhibit the marks of the reed; Gothic or Black Letter writing reveals the introduction of the quill. The serif (the fine lines or cross strokes in printed letters) are actually remnants of the chisel marks made in cutting stone.

These ancient forms of writing have fallen into great neglect, although the designers of new types turn back to them repeatedly as sources of their inspiration and it is astonishing how many large users of printed matter honestly believe they have adopted something sensationally new when, as a matter of fact, they are using a type face which bears the patina of a respectable age.

The "Art Preservative of All the Arts" boasts a fine traditional past. Despite the competition of radio, motion pictures, and television it has a bright future and, as long as illustration and design continue to improve, the printed word will remain the chief factor in the transmission of ideas.

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from 9 A.M. until 5 P.M.; Wednesdays and Thursdays from 2 P.M. until 10 P.M.

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JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in the JOURNAL within the next few months:

SYMONDS, P. S.: Recent Progress in the Plastic Methods of Structural Analysis.
MANDEVILLE, C. E.: The Slow Neutron Induced Radioactivities of Nuclear Explosions.
KRZYWOBLOCKI, M. Z.: On the Foundations of Certain Theories of Turbulence.
SPENCER, DOMINA EBERLE AND CYNTHIA SANBORN: Interflections and Color.
GEORGE, E. F.: Light—Inadequacy of the Ultraviolet Theory of Ionization in the E-Layer.
SILBERSTEIN, LUDWIK: Superposition or Mixture of Simple Quantic Characteristic Curves of Photographic Emulsion Layers.
GOLOMB, MICHAEL AND EUGENE USDIN: A Theory of Multidimensional Servomechanisms.
MCCLESKY, CHARLES S., JR.: Resistance of Plates with Small Electrodes.
MOON, PARRY AND DOMINA EBERLE SPENCER: Cylindrical and Rotational Coordinate Systems.

THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

The following papers, prepared by staff members of the Laboratories and published in various technical journals, are available in reprint form, in limited quantities upon request. Please address inquiries to the Administration Division of the Laboratories, Benjamin Franklin Parkway at 20th, Philadelphia 3, Pa.

	Subject	Author
1.	High Accuracy Contour Cams	R. O. Yavne
2.	A Spiral Chronograph for Long Time Intervals	H. D. Warshaw
3.	A New Method of Sectioning Synthetic Fibers with the Ultra-Microtome for Examination with the Electron Microscope	Dr. M. D. Earle and Mrs. Jean Minkin
4.	Research Work of The Franklin Institute During World War II on Airborne Fire Control Apparatus	R. H. McClarren
5.	Application of Experimental Test Procedures and Methods of Analysis of Results to Research Problems in Magnetic Recording	C. S. Thompson
6.	Physical Testing of Asphalts and Similar Materials	Edmund Thelen
7.	Combustion Studies Using the Golay Photothermal Detector with an Infrared Monochromator	Dr. J. T. Agnew
8.	Combustion Studies with the Orthicon Spectroscope	Dr. J. T. Agnew, R. Franklin, R. Benn, and A. Bazarian
9.	The Image Orthicon in Spectroscopy	R. Benn, W. Foote, and Dr. C. T. Chase
10.	Convertible Aircraft	R. S. Barnaby, S. M. Berkowitz, and W. H. Colcord
11.	What About Friction?—Parts I, II, and III	Dr. Frederic Palmer
12.	An A-c. System of Remote Indication and Its Application to the Measurement of Fluid Pressure and Control	H. D. Warshaw
13.	Rotor Balancing with an Electronic Capacitor Gauge	H. D. Warshaw
14.	Mechanical Computing Mechanisms—4 Parts	R. R. Reid and DuRay E. Stromback
15.	Measurement of the Spin of a Projectile in Flight	H. D. Warshaw
16.	A Simple Television Demonstration	Robert E. Benn
17.	Film-Pressure Distribution in Grease-Lubricated Journal Bearings	Gunther Cohn and *Jess W. Oren
18.	The Basis for the Optimum Aided-Tracking Time Constant	E. A. Mechler, **Prof. J. B. Russell, **Dr. M. G. Preston
19.	A New Fourier Coefficient Harmonic Analyzer	S. Charp
20.	The Airflow Slide Rule	Lisbeth Crowell
21.	A High-Attenuation Filter for Harmonic Suppression	A. M. Pichitino
22.	Assembly of Thin-Walled Parts by Rubber Crimping	Frank R. Simpson
23.	Factors Affecting the Precision of Viscosity Measurements with the Torsion Crystal	P. E. Rouse, Jr., E. D. Bailey, and Jean A. Minkin
24.	Stress Distribution Around Spot Welds	A. O. Bergholm, P. W. Swartz, and G. S. Hoell
25.	Electrets	Dr. W. F. G. Swann
26.	On Certain Matters Pertaining to Electrets	Dr. W. F. G. Swann
27.	Control Mechanisms for Hydraulic Piston Pumps	W. B. Strickland
28.	Radial Engine	G. S. Hoell
29.	Random Circuit Theory of Resistance and Noise in a Composition Resistor	Dr. R. P. Coleman
30.	A Ten Channel Infrared Spectrograph	Dr. J. T. Agnew, R. G. Franklin, and R. E. Benn

* Research Engineer, Armstrong Cork Company, Lancaster, Pa.
** Consultants to Laboratories: Prof. J. B. Russell—Columbia University Staff; Dr. M. G. Preston—University of Pennsylvania Staff

BOOK REVIEWS

QUANTUM MECHANICS OF PARTICLES AND WAVE FIELDS, by Arthur March. 292 pages, 15 × 23 cm. New York, John Wiley & Sons, Inc., 1951. Price, $5.50.

This is in no sense another introductory book on quantum mechanics. Rather, it represents a contribution by one who has followed and taught the subject for a quarter of a century, finding numerous incongruities which needed improvement. Arthur March has taught at the University of Innsbruck, Austria, for nearly thirty-five years. His first book on the foundations of quantum mechanics was published in 1930 but has never been translated into English, nor has it found wide acceptance in this country (very few libraries carry it).

In these times, when our libraries are bulging with scientific works, every new volume requires some justification. It is understandable that a volume of this sort should appear now, written in English and published in the United States, because of the significance placed in this country upon the study of nuclear particles.

The book is intended as a text and as a summary book for the modern physicist. The author summarizes principles in the first half of the book and then tackles some of the unexplained newer problems with which other texts have not dealt.

The late 1920's, in which the knowledge of atomic structure and resulting interpretation of spectroscopic and electronic phenomena became a force, were the most active in the history of theoretical physics. The works of Heisenberg, De Broglie and Schrödinger led to a flood of books on the subject of quantum mechanics and its rapid development from 1930 on. Most well equipped technical libraries have on their shelves at least one hundred volumes on quantum mechanics dating from that time.

Professor March's book attempts to interpret the meaning of "field" in the new mechanics. Special care has been taken to acquaint the reader with the mathematical formalism of relativistic quantum mechanics. Specifically, the author discusses wave mechanics of single and many particle systems, stationary states and matrix form, perturbation theory, quantization of wave fields, and quantum electrodynamics. Finally he introduces the idea of fundamental length in an effort to eliminate the difficulties which arise when the principles of quantum mechanics are applied to electromagnetic fields. This fundamental length is shown to be of similar significance to Planck's constant, h, and the light velocity constant, c.

In the usual manner he covers Heisenberg's quantum mechanics, De Broglie waves, Bohr's theory, wave mechanics of Schrödinger, electron spin, as well as the achievements of the theory for one-body and many-body problems, and interpretation of the theory in Heisenberg's Uncertainty Relations.

One great criticism of this volume concerns the manner in which it is presented; that is, the reader is assumed to have complete familiarity with the literature. There is scarcely a reference in the book, and in a controversial field such as quantum mechanics in which there is not complete agreement among physicists, it seems that the student might wish to examine the evidence beyond the brief confines of Professor March's 292-page book. Most texts on this subject supply numerous references dating back to 1900 in order to give understanding to the difficulties encountered in classical quantum theory and the leading ideas which mitigate these difficulties. Besides presenting a problem for the student, the lack of appropriate references gives the impression that the material presented is largely original with the author which is not the case.

If used for teaching purposes, the volume should be heavily supplemented with other books giving details of experimental results upon which the theory is based such as Goudsmit and Pauling's "The Structure of Line Spectra" and Ruark and Urey's "Atoms, Molecules and Quanta." In spite of some difficulties which the author may have experienced writing a book of this type in other than his mother tongue, which fact undoubtedly accounts for some sacrifice in expression, the book provides a text which may help clarify the latest conceptions and mathematical formalism of the theory of fields and particles.

C. W. HARGENS

ANALYSIS OF THE FOUR BAR LINKAGE, by John A. Hrones and George L. Nelson. 13 pages of text and 730 pages of charts, 29 × 44 cm. Published jointly by The Technology Press of The Massachusetts Institute of Technology and John Wiley & Sons, Inc., New York, 1951. Price $15.00.

The simplest of all the linkage combinations is the four-bar linkage; it may be regarded as being a basic mechanism. This combination consists of two rocker arms which are pin-connected at each end to links, one fixed and the other free to move. In seeking a method of analysis of this combination of links, one is confronted with the choice between a mathematical or a graphical approach. The equations which describe the displacement, velocity, and acceleration of points on the connecting rod are long and unwieldy, making mathematical synthesis a very tedious process which few designers are willing to undertake. In this volume, the authors have made available to the engineering world an exhaustive survey, in graphic form, of the displacement and velocity characteristics of a four-bar linkage in the range of operation where the driving crank makes a complete revolution while the follower crank oscillates.

This volume is divided into two distinct parts. The first, pages vii to xx, is devoted to a general discussion of the four-bar linkage and to an explanation of the use of the charts. The remainder, pages 1 to 730, consists of charts bearing the displacement trajectories of a network of points on the connecting rod of a four-bar linkage for a wide variety of link ratios.

The four-bar linkage is broken down into three classes, based on the type of linkage operation. Class (a)—One crank is capable of rotation through a complete revolution while the second crank can only oscillate. Class (b)—Both cranks are capable of rotating through a full circle. Class (c)—Both cranks oscillate, but neither can rotate through a complete revolution. Examples of each class of linkage appear in the discussion, and a classification chart is provided which is based on the ratios of each of the links to the shortest link. It is intended to aid the designer in determining whether or not his particular linkage set is within the scope of this volume.

Six illustrated examples are provided to depict the varied uses to which the four-bar linkage combinations can be used. They are: the dwell period from straight-line path, dwell period from circular-line path, computer linkages, double oscillating crank, and symmetrical-motion paths. Consideration is also given to velocity and acceleration determination.

The charts give directly the motion characteristics of many linkages. The material appears in sets of five charts. Each set covers motion characteristics of a given linkage. The sets form groups. In each group two of the basic link ratios are held constant while the third is progressively varied. The points on the connecting rod whose trajectories are shown on the chart are indicated in the title block.

Besides serving as an invaluable tool to those who are concerned with the development of simple linkage forms, this volume will serve as a stepping stone to the design of more complicated forms of linkages. The fullest use of this volume is limited only by the imagination of the user.

T. J. BOWDEN

ADVANCED FLUID DYNAMICS AND FLUID MACHINERY, by R. C. Binder. 426 pages, illustrations, 14 × 22 cm. New York, Prentice-Hall, Inc., 1951. Price, $6.00.

Professor Binder's book, *Fluid Mechanics*, was used extensively during, and since, World War II in grounding students in the fundamentals of the mechanical behavior of fluids. *Advanced Fluid Dynamics and Fluid Machinery* is an extension of his previous book.

This book is an outgrowth of course work and mimeographed notes presented at Purdue University, and articles published by the author in professional journals. Physical concepts and basic quantitative relations are stressed. Analogies are used both in introducing subjects and in analyzing them.

The material is divided into three parts "for a more balanced, practical presentation." Part I gives the classical presentation of one-dimensional compressible flow with friction and heat transfer, and boundary layer flow. Seven excellent shadow photographs of spheres,

cylinders, and cone-cylinders moving at supersonic speeds, are presented by the Ballistic Research Laboratories and printed; however, the experimental apparatus employed is not explained, and the photographs are not adequately interpreted. Stress is placed upon the equation of continuity, momentum relation, and the energy equation. The illustrations are well chosen and reproduced. They both illustrate the basic principle and present to the reader the practical applications of the principle. Part II offers common illustrations and applications of fluid machinery, exemplifying the theories presented previously. The illustrations are generally confined to torque converters and pressure-raising devices, and do not cover all of the theory of Part I. Part III is an extension of Part I to unsteady flow, and flow in two dimensions. An analysis is made of the unsteady flow in mufflers, fan surging, water hammer, and certain fluid induction problems. The study of the two-dimensional flow of incompressible and compressible fluids is kept quite general. The mathematical techniques and analytical relations which are needed are carefully explained.

The author includes no illustrative problems in the book. Suggested problems average just over four per chapter. The value of the book would be enhanced for either reference or study if it contained more illustrative and suggested problems.

The wisdom of separating theory and application in an engineering textbook is always open to question. The decision may be based upon the complexity of the application or the Curriculum which must be followed. If Part II of this book intends to illustrate and apply the material of Part I, then perhaps Part II has been limited to one branch of Mechanical Engineering when there was an opportunity to apply Part I to a larger area.

A. D. HAY

SYNCHRONOUS MACHINES, THEORY AND PERFORMANCE, by Charles Concordia. 224 pages, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1951. Price, $5.50.

Electrical power engineers who design or use synchronous machines and systems and graduate students interested in a more detailed study of these machines will want this text.

Synchronous Machines presents a physical and a mathematical description of synchronous machines, discusses three-phase and single-phase short circuits, short circuit torques, starting-torques and voltage dips. Both steady state and transient solutions are obtained by developing a great number of formulas. The mathematics used will present no difficulty to the graduate electrical engineer.

The author carefully develops the machine performance in terms of the direct, quadrature, and zero sequence components. Throughout the rest of the book, the behavior of the machines under various system conditions and faults are analyzed.

In this process the author stresses the different approaches, such as: the use of a constant flux concept to solve sequential fault problems, symmetrical components to understand double-line-to-ground faults, and simplified equivalent circuits to present various problems. No one approach is the best for all problems and several methods may well be used on one problem. The easiest methods should be used.

Most of the cases analyzed are solved by approximations. However, the author points out what these approximations are and how well they fit the actual case. The answers obtained have engineering accuracy and are very useful in understanding the basic theory and performance of the machines. In some cases, an exact analysis is of no use because of its complexity.

Selected problems and a well rounded bibliography complete this mathematical treatment of synchronous machine theory and performance.

E. A. MECHLER

THE SCIENTIFIC PAPER, by Sam F. Trelease. Second edition, 162 pages, illustrations, 13 × 19 cm. Baltimore, The Williams & Wilkins Co., 1951. Price, $2.50.

Research workers, confronted with the arduous task of preparing reports on the results of their work, will find this manual of inestimable aid, for it contains *practical* suggestions on how to present technical material in the best possible form. A scientist is judged by the

quality of his final product—the published results of his work; if he does a poor job of writing, his work may well be judged poor, also. A careful study of this book will help the scientific author to present his material forcefully, concisely and clearly.

First published in 1947 under the title *Preparation of Scientific and Technical Papers*, the present work has been thoroughly revised and largely rewritten, with the subject matter organized into seven chapters covering: The Research Problem, Writing the Paper, Good Form and Usage, Tables, Illustrations, Publication Preview, and Proofreading. A bibliography and an index complete the contents.

As an editor, this reviewer commends especially the chapters "Writing the Paper" and "Illustrations." The former offers advice on the form of the typewritten manuscript which, if followed, materially aids the editors who must prepare the copy for the printer. One such helpful suggestion is to put on separate sheets all material, such as footnotes, figure captions, references, etc., which are to be set in different sizes of type. This chapter also lists devices to make the paper interesting and gives rules for making corrections on the manuscript. The chapter on illustrations sets forth not only the physical requirements necessary to produce good illustrations from drawings and photographs—such as type of ink, paper, composition of photographs, size of originals, etc.—but also advises the author on such fine points as how to number the illustrations, how to indicate what size they are to be when finished, and even how to ship them.

Also, any editor who has spent considerable time wondering just what the authors mean by the extraordinary proofreading symbols on their corrected proofs will applaud the short section on proofreading, including a list of the standard symbols.

The Scientific Paper should be carefully studied by all scientific writers who hope to publish any of their work.

N. S. GLENN

THERMODYNAMICS OF FLUID FLOW, by Newman A. Hall. 278 pages, tables and drawings, 15 × 22 cm. New York, Prentice-Hall, Inc., 1951. Price, $5.50.

As Professor Hall of the University of Minnesota remarks, recent developments in the field of mechanical, chemical and aeronautical engineering have established the importance of a knowledge of both thermodynamics and fluid mechanics in the study of fluid flow. Accordingly, he has presented, in *The Thermodynamics of Fluid Flow*, the subject of fluid flow from the combined viewpoint of fluid mechanics and thermodynamics. Although some review of fundamental principles is presented of necessity, the book is not an elementary text; it is supposed that the student has had basic training in fluid mechanics and thermodynamics.

Written in a succinct style with a minimum of words, the book is short, less than 200 pages, exclusive of an appendix. At the same time, however, much material is covered. Following an introduction where the importance of thermodynamics in fluid flow analyses is discussed, succeeding chapters are concerned with fluid friction, energy and continuity, momentum principles, and incompressible fluids. Other chapters treat perfect gases, constant- and varying-area adiabatic flow, shock regions, flow measurement and control, diabatic flow, and propulsion systems. The appendix, containing tables of conversion factors, mathematical notes on binomial approximation, logarithmic and partial differentiation, thermodynamic partial derivatives and various gas tables, adds to the usefulness of the book. Also, the author has wisely included a number of illustrative problems in the explanation of the various subjects.

E. W. HAMMER, JR.

PRINCIPLES OF CHEMICAL THERMODYNAMICS, by Martin A. Paul. viii plus 740 pages, illustrations, 15 × 23 cm. New York, McGraw-Hill Book Co., 1951. Price, $7.50.

The outstanding quality of that historic book on chemical thermodynamics by Lewis and Randall long discouraged any competition. However, the many recent developments have made a more modern book on the subject necessary. In recent years a number of such books have appeared. Unfortunately, few authors possess the genius of the late G. N. Lewis,

apparently necessary for a concise and exact presentation of this abstract and difficult subject. The present volume represents a good try, but is notable mainly for its size.

According to the preface the book is intended as a text for Senior or first year graduate students. It is written in the form of a text, with a number of problems at the end of each chapter. The book is entirely too long, however, for this purpose. The author also has not recognized the psychological hazard of long chapters. Several of the chapters are ridiculously long; four of the ten chapters are seventy or more pages, and one is 181 pages!

Much of the length of the book is due to the inclusion of subjects related to thermodynamics but not strictly belonging to the subject: temperature measurement, kinetic energy, bond energies, lattice energies, surface tension measurement, and many others. The inclusion of these subjects may help to explain many of the phenomena observed in thermodynamics. But they are not strictly part of thermodynamics and their inclusion not only adds unduly to the length of the book; it also tends to confuse the truly empirical nature of thermodynamics, which is both its strength and its weakness.

The usual subject matter of chemical thermodynamics is included: the three laws, and their applications to gases, chemical reactions, phase rule, solutions, galvanic cells, etc. The various equations are derived successively in the usual semirigorous manner. However, some of the mathematics is rather difficult, and many of the explanations do not seem as clear and concise as they might be. Numerous examples of specific applications are given. The final chapter gives a statistical development of the thermodynamic functions. Most of the problems are based on recent data in the literature. They are mostly rather long, and there are far more than anyone could solve in any reasonable time.

In the opinion of the reviewer the book is not adequate as a text. It is entirely too long, and the explanations do not always seem adequate. It would seem more suitable as a review for someone who has studied the subject many years ago and wishes to read up on forgotten points and more recent developments. Some of the specific applications, such as the long sections on gaseous mixtures, are more suitable for the reviewer than for the beginner. The cost of the book is reasonable in view of its size.

N. W. MCCREADY

A FLIER'S WORLD, by Wolfgang Langewiesche. 278 pages, illustrations, 15 × 21 cm. New York, McGraw-Hill Book Co., Inc., 1951. Price, $3.75.

This is not the sort of book one would usually find in a technical library. However, as Frederick Lewis Allen says in his foreward to the book, "*A Flier's World* will appeal to everyone who has ever felt an inner lift from watching a plane in flight. Wolfgang Langewiesche, one of America's foremost pilots, has that rarest of writer's gifts—the ability to make you actually live his subject." The oft-believed complexities of flight are vividly translated into terms that anyone can grasp. He makes technical facts clear to the outsider and aviation-minded people alike, all without the use of one single formula!

Four major chapters on the fundamentals of flight and flying are presented. Included are discussions of the three secrets of human flight, what makes an airplane fly, blind flying, high-speed flight, ocean flying, what makes the weather, air currents, personal flying, domestic and foreign flight, to mention just some of the highlights.

Presented in such an interesting and brilliant manner, *A Flier's World* is a welcome addition to any library, technical or non-technical.

SAMUEL M. BERKOWITZ

BOOK NOTES

ALKALI SOILS, by W. P. Kelley. 176 pages, diagrams and tables, 16 × 24 cm. New York, Reinhold Publishing Corp., 1951. Price, $5.00.

This monograph is an excellent treatise on alkali soil, written for use of research workers and teachers in the field of soils, soil conservation and related subjects. Basic principles are stressed, namely: processes by which soluble alkali salts are formed and means of accumulation; the chemical, physical and microbiological effects, with a lengthy discussion of base exchange; and plant growth. The relationship of irrigation and drainage to reclamation of soil in arid and semi-arid regions is discussed. Review of work of previous investigators and a selected bibliography are included.

ROUTE SURVEYS, by Harry Rubey. Revised edition, 314 plus 282 pages, plates, illustrations and tables, 12 × 18 cm. New York, Macmillan Co., 1951. Price, $5.25.

This is a carefully revised and modernized edition of text material for use of students of civil engineering in curves and earthworks as they apply to various aspects of transportation as stated in the title. Fundamentals underlying modern trends are stressed, and incorporated in the text are numerous tables, figures and formulas of practical value.

Revised material includes, in part, arc and chord definitions of degree of curve in parallel; A.R.E.A. ten-chord spiral; string lining; railway turnouts; practice in use of aerial photography and photogrammetry; and references on standard soil data, soils stabilization and profiles.

MARINE GEOLOGY, by Ph. H. Kuenen. 568 pages, plates and diagrams, 15 × 23 cm. New York, John Wiley & Sons, Inc., 1950. Price, $7.50.

Only within the last two decades interest has been focused on geology of the sea. The author has emphasized in this text information concerning submarine land forms and their interpretation, sedimentary cover of the sea floor, structure of atolls, submarine canyons and Moluccan deep-sea troughs.

Summarization of present knowledge and problems to be solved, as well as references to original source material aids the reader interested in obtaining further detailed information. The book is a specialized text and would be of interest to advanced students and scientists in the field of marine geology.

ELECTRICAL INSULATION: ITS APPLICATION TO SHIPBOARD ELECTRICAL EQUIPMENT, by Graham Lee Moses. 259 pages, illustrations, 19 × 26 cm. New York, McGraw-Hill Book Co., Inc., 1951. Price, $5.50.

Data have been compiled in manual form on electrical insulation methods and materials with regard to specific application and design of high-temperature insulation in ship construction. The basic concepts, function and selection of insulation materials, testing procedures for equipment, and specific "do's and don't's" of installation and maintenance are clearly presented. The problem of general wire and commutator construction, apparatus assembly and winding are included. Manual stresses the new in current practice and newest in materials to aid in solving problems involved in the operation, maintenance, and storage of ships' electrical equipment.

ANALYTIC GEOMETRY, by John W. Cell. Second edition, 326 pages, diagrams, 14 × 22 cm. New York, John Wiley & Sons, Inc., 1951. Price, $3.75.

Arranged for use in a five-hour, one-semester course, *Analytic Geometry* presents a fresh approach to an old subject, by making use of numerous illustrations and problems in science and engineering. The material, in preparation for fourteen years, has been tested in actual classroom situations, and provision has been made for the superior student, with marked problems. Aimed primarily for engineering, science and mathematics majors, it fills the gap between analytic geometry and subsequent courses in mathematics and science.

Single Column Gauges (*Instrument Practice*, Vol. 5, No. 8.).—The Type 141 series of pressure and draught gauges, made by the Metronic Instrument Co., Ltd., Ettingshall, Wolverhampton, has recently undergone major changes in construction.

The most important modification is the method of joining the ends of the glass tube to their metal companions. The pressure connection is a combination gland pressure screw and solderless union. The pressure screw squeezes a synthetic rubber ring direct on to the glass tube end, making a perfect seal which will hold even though pressure is taken up to bursting point of the metal reservoir. The other end of the glass tube is similarly sealed to a steel or copper tube which runs direct to the reservoir.

Although the normal guaranteed maximum working pressure for gauges connected differentially is 150 lb. per sq. in., the new Type 141 gauge is now regularly used in large quantities for measuring oxygen pressure drop in a system under a pressure of 300 lb. per sq. in. The Type 141 gauge series covers the entire range of pressures, draughts and differentials from 0–1 in. w.g. up to 0–60 in. Hg. The machine-cut scales are contracted to about 97 per cent to provide direct reading of an extremely high order of accuracy. All steel parts are walterized; this means that any gauge may be used for either water of mercury filling.

Flow measurement of gas, liquid or steam is catered for by these gauges; flow gauge scales are graduated in any desired flow units.

British Study American Industry.—Under the auspices of the Anglo-American Council on Productivity and the Economic Cooperation Administration, a group of 17 British executive and production workers in the zinc and aluminum die casting industry visited the plant of the AJAX Engineering Corporation in Trenton, New Jersey, recently, as the first stop during an extensive tour of American industries.

Their objective is to study administration, layout, plant methods and operating conditions in the American zinc and aluminum die casting industry, together with a study of the applications made in this country of such die cast products. These United Kingdom Productivity Teams include representatives of management, technical experts and labor. Such a choice of team members has been found effective in studying productivity problems here, in helping their counterpart industries in Great Britain, and also in acquainting the peoples of their country with the possible benefits to them resultant from increased national productivity. The plant visits are arranged on a management and labor cooperative basis. In this way the British are enabled to obtain an impression of the intangible factors as well as the technical developments which increase production in the United States.

At the AJAX plant both the manufacture and the operation of low frequency electric induction furnaces were explained to the visitors by means of motion pictures, lectures and a trip through the plant. During lunch, a question-and-answer period cleared up any technical questions that might have remained unanswered in the earlier sessions. Following this, the group journeyed to the Trenton plant of the Ternstedt Division of General Motors, where an AJAX Electric Furnace was viewed in actual operation.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE MCDONALD, DIRECTOR

The Influence of Protein Depletion on the DNA Content of Nuclei of the Pancreas and Small Intestines of the Rat.—J. O. ELY AND M. H. ROSS. It was shown recently by both chemical and cytochemical methods that during protein depletion caused by feeding a protein-free diet, or a 12 per cent casein diet, the desoxyribonucleic acid (DNA) content of the nuclei of rat livers increased.[1] This work has now been extended to the nuclei of the rat pancreas and small intestine. The chemical method for DNA estimation was used for the nuclei from the intestine and the photometric method applied to Feulgen-stained sections was used to compare the amount of DNA in the nuclei of the pancreas.

Rats of the Wistar Strain were maintained on 1) Fox Food Blox diet and 2) a protein-free diet for 15 to 51 days. Nuclear suspensions from the small intestines were prepared by the use of 5 per cent cold citric acid, a Waring Blendor and centrifugation. Pancreatic tissue was fixed in commercial formol diluted 1:1 with distilled water. Sections were cut 3 microns in thickness. Tissues to be compared were always embedded in the same block of paraffin, cut by the same stroke of the microtome knife; the sections were mounted on the same slide, and photographed on the same strip of film with the same exposures and development. The photometric comparisons of the intensity of Feulgen color were made as previously described.[1] Over 200 nuclei per section were used, or a total of approximately 2,000 for each diet.

RESULTS

The nuclei from the small intestines of the rats fed the protein-free diet contained approximately 13 per cent more DNA per nucleus than did the nuclei prepared from the small intestines of the rats fed the Fox Food Blox diet (Table I). Statistically, the difference is significant.

TABLE I.—*Comparative Amount of DNA in Nuclei.*

	Intestine (Chemical Method)		Pancreas (Photometric Method)	
	Mg. of DNA per nucleus		Relative amount of DNA in nucleus	
No. of Rats	Protein-free diet	Fox Food Blox diet	Protein-free diet (Extinct.Coeff.)	Fox Food Blox diet (Extinct.Coeff.)
10	$0.71(\pm 0.043^*)\times 10^{-8}$	$0.627(\pm 0.034)\times 10^{-8}$	1.007 ± 0.039	0.600 ± 0.027

* Standard error of mean.

[1] J. O. ELY AND M. H. ROSS, *Science*, **114**: 70 (1951).

The nuclei in sections of pancreas from the rats fed the protein-free diet were found to contain approximately 68 per cent more DNA than did the nuclei from the rats fed the Fox Food Blox diet (Table I).

The difference found for the nuclei of the intestine was somewhat less than was found earlier for the liver by the same method.

The difference found in the pancreatic nuclei by the photometric method was slightly greater than the difference found for hepatic nuclei by the same method.[1]

The results indicate that during protein depletion caused by feeding a protein-free diet to rats the DNA content increases in the nuclei of the small intestine and the pancreas as well as in the liver as previously shown.

CURRENT TOPICS

New Clusters in Space Charted by Sky Survey.—Eight hundred new clusters of nebulae—great masses of gas and stars at incredible distances out in space—have been discovered by the new 48-in. Schmidt telescope at Palomar Mountain, the National Geographic Society and the California Institute of Technology have announced.

Photographs of the new clusters taken with the Schmidt Sky Survey telescope and the Hale telescope at Palomar have furnished new data to astronomers implementing the theory that the entire universe is expanding at speeds comparable to the speed of light.

Distant clusters never before seen—the farthest some 350 million light years away—have been found to follow the "law of red-shifts," Dr. Milton Hunason of the Palomar Observatory staff disclosed to his colleagues of the Astronomical Society of the Pacific. They range out to the extreme observable limit of the Schmidt telescope, and finding more distant clusters—beyond the reach of the Schmidt—must hereafter depend upon pure chance, Dr. Humason said.

Only about 20 such massive systems in space were known prior to the start of the National Geographic Society-Palomar Observatory Sky Survey in 1949. The 800 others have been found in the last two years.

"Red-shifts"—the amount by which light from star clusters is moved toward the red end of the spectrum—indicate to astronomers in what direction a nebulosity is moving. The red-shift brought about the formulation of the basic theory of an expanding universe about a quarter of a century ago. Moreover, the "red-shift" affords astronomers a measure of the speed at which other members of the universe are rushing away from the Earth's own solar system.

This "red-shift" property of light is similar to the change in tone of a train whistle as it rushes by a person standing still. The whistle is higher as the train approaches, lower after it passes, than if the train were stopped. Wave-length of light is likewise lowered, or reddened, by stars moving away from the earth, astronomers now believe.

From the new discoveries, speeds at which clusters of nebulae are moving out in space have been shown to increase in direct proportion to their distance. The most distant cluster clocked in the Palomar studies is traveling about 38,000 miles per second—more than one-fifth the speed of light itself. Light that reached the big Schmidt telescope began its travel more than 350,000,000 years ago, when the Earth was young and man did not exist.

These discoveries are among the first fruits of a four-year Sky Survey, to be completed in 1953, which is the joint project of the National Geographic Society and Cal Tech. The Survey will map the entire sky visible from Palomar out to 350 million light years.

When the project is finished a Sky Atlas will be published which is expected to record some 500 million stars, perhaps 10 million complete stellar systems of extragalactic nebulae and other astronomical phenomena.

Photo-Nephelometer Spotlights Impurities in Serums and Beverages.—Like a stream of sunlight exposing millions of dust particles as it enters a

room, a man-made ray of light is being used to show up impurities in industrial products.

The probing light shines in a small laboratory instrument called a Photo-nephelometer, made by Coleman Instruments, Inc., Maywood, Ill. Important to the accuracy of the device is a constant voltage transformer, provided by the Sola Electric Company, Chicago.

The Photo-nephelometer is used in hospitals and research laboratories to detect bacterial contamination in serums; in distilleries to measure unappealing cloudiness in whiskies; and in many other places where unwanted matter might easily wander into liquid, destroying its utility or attractiveness.

The constant voltage transformer is necessary to make sure that the intensity of the light does not vary as a result of fluctuations in voltage from the source. The Sola transformer, connected to the Photo-nephelometer, provides a steady stream of current at 6.0 volts, 60 cycles, on which the instrument operates properly.

Voltage fluctuation adequate to cause improper measurenent is common virtually throughout the country, Sola finds. A great many buildings are not adequately wired to handle their increasing electrical burden.

In operation, the unit is like a sunbeam bouncing off dust particles, in that the light in the instrument is deflected by undesirable matter. This haze is often invisible to the naked eye.

Among other applications, the instrument has detected calcium, magnesium, chlorides, and other impurities in water used in high pressure boilers. Any of these substances threaten the efficiency of modern boilers operating at high pressure.

The Photo-nephelometer is about the size of a small adding machine, and can be operated by the average laboratory technician. A scale on the face of the instrument registers the amount of haze in the liquid being examined.

The name of the device comes from the Greek "nephelos," meaning clouds.

Novel Technique Tracks Underwater Mud Layers and Bedrock Structure.—Completion of a Geological Survey mapping program tracing the depth of bedrock along Chicago's Lake front has been announced by Secretary of the Interior Oscar L. Chapman. A technique, involving sonar depth finding, was developed that has never been used before.

Chicago is planning construction of a new filtration plant and distribution system to be located north of Navy Pier to provide an additional supply of potable water from Lake Michigan. The present South Side pumping and purification plant is already one of the largest in the world, but the new one will be three times as large. It is estimated that it will cost approximately eighty-five million dollars.

Chicago's Commissioner of Public Works, Oscar E. Hewitt, explained that because it is intended to construct a distribution tunnel more than five miles long and sixteen feet in diameter underneath the harbor paralleling the water front, it was important to know beforehand the configuration of bedrock along the proposed route. The tunnel will be constructed about fifty feet below the top of the limestone bedrock to prevent contamination of the water after it leaves the filtration plant. Information on subsurface conditions was also needed for the filtration plant itself.

In the course of their work the Geological Survey engineers and geologists located two hidden valleys in the bedrock, both buried beneath an overburden of mud and silt. One was 130 feet deep and two miles long, more or less paralleling the shore and making an abrupt turn to the southeast to join a larger valley, once part of an ancient southeasterly trending drainage system. The other is six miles to the north and about 80 feet in depth. It was traced for four miles out into the lake. In addition, several other deep depressions were located along the proposed tunnel route, which means the tunnelers will be forced to work at a considerable depth in order to prevent entry, or "holing out," into soft mud. The bedrock configuration, characterized by modified karst topography (brought about by the action of water upon limestone) bears no relation whatever to present surface features like Belmont Yacht harbor and the lake shore. These were determined largely by the action of Pleistocene glaciation.

The usual method of attacking a mapping problem of this sort would have been to make innumerable rock borings along the intended route of the tunnel and at the site of the sixty-one acre filtration plant. This would have been expensive and taken considerable time and equipment. Now it will be necessary to drill only about six test holes at key points to tie in the plotted bedrock contours.

City Engineer, W. W. DeBerard, through Oscar E. Hewitt, Chicago Commissioner of Public Works, requested Federal assistance with this initial geological problem and the work was assigned to W. O. Smith of the Geological Survey's Ground Water Branch.

Arrangements were made with the Navy Bureau of Ships, Electronics Division, to use new electronic depth-finder equipment capable of measuring not only the depth to the top of the mud and gravel layers, but by penetrating these to determine the depth to bedrock itself. In this work a principle similar to that of the fathometer is used. A signal is given off and its time of travel to where the bedrock reflects it upward is measured. The distance to these layers is automatically computed by the instrument and soundings are recorded continuously on graph paper.

Thus by plotting the depth to the various rock layers recorded by the depth-finder, as the ship traversed a series of more or less parallel courses, a group of profiles was defined upon which elevation contours were readily plotted. The equipment used was a standard depth-finder made by the Edo Corporation, College Point, Long Island, New York, for the United States Navy. It operates on the sonar principle, using a sonic signal given off by what is known as a transducer.

The plan of sonic sounding courses was laid out by Mr. Smith and accomplished during August 1950. A 60-foot tug belonging to the city of Chicago was used to carry the equipment and co-operating engineers. The transducer was slung over the side from a davit. John Campani, an Edo Corporation electronic engineer, installed and operated the equipment for the project. The map of bedrock topography was completed by G. G. Parker, geologist with the Survey Ground Water Branch, using data obtained from the sonic soundings.

Careful sextant work was required to furnish direction control for the sounding course, through sights taken on Wilson Avenue, Carter-Harrison and

four mile intake cribs. This work was done by personnel of the Department of Public Works. Dr. M. M. Leighton, Director of the Illinois Geological Survey, and Mr. George Otto, Chicago consulting geologist, gave valuable aid through data on numerous boring records in their files.

Electric Label Dispenser (*Modern Plastics*, Vol. 28, No. 11.).—Mechanization of hand-labeling operations is made possible by the new E-350 electric label dispenser developed by Avery Adhesive Label Corp., Monrovia, Calif., for its Kum-Kleen Self-Adhesive Labels. The automatic device, claimed to increase labeling speed in some cases by 500%, is said to eliminate moistening, heat, sorting of loose labels, and the messiness of excess glue.

A span of accurate speeds ranges from 10 to 50 lineal inches per minute. The machine can be stopped and started with split-second precision. Foot switch controls are provided when intermittent operation is desired; in such cases, a predetermined speed rate (controlled by a rheostat) resumes automatically.

Model E-350 can handle labels from ½ to 3 in. wide, and from ⅛ to 6 in. long. It is designed as a compact, portable unit which fits into any production line.

Portable Power Threader (*Gas Age*, Vol. 108, No. 1.).—A new light weight portable power pipe threader, the Port-A-Pony, has been developed by the Thread-Ezy Mfg. Co. of Corunna, Mich., to take the work out of threading ¼″ to 4″ pipe on the job.

The Port-A-Pony is particularly useful to gas utilities who use large amounts of threaded pipe 4″ or less in diameter. With a carrying weight of only 26 pounds, the Port-A-Pony is easily operated or transported by one man. It can be used either in the field or in the shop. The exclusive "ring-gear" principle used in the Port-A-Pony turns regular die stocks at the proper cutting speed for top efficiency.

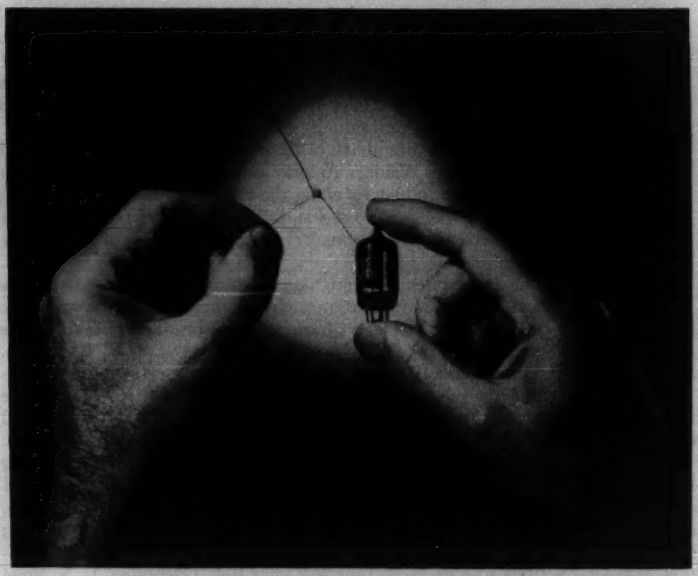
All popular types of hand die stocks are adaptable to the Port-A-Pony, eliminating the need to buy a new set. Dies can be changed, seated and locked in place in a matter of seconds, increasing the adaptability of the unit. Additional speed in operation is obtained by the ½ h.p., 110 volts a-c. or d-c. reversible electric motor which removes the Port-A-Pony from finished threads by the flip of a switch.

Telescopic Lift (*Chemical and Engineering News*, Vol. 29, No. 28.).—A design innovation that permits standard 83-inch over-all height telescopic lift trucks to "reach for the sky" and tier loads in greater than 16-foot stacks has been announced by the Philadelphia division of Yale & Towne Mfg. Co. This new development is expected to enable distribution and transportation companies as well as industrial concerns to utilize storage space now considered critical both from a cost and availability standpoint.

The device consists of an extra set of front channels and an additional lifting cylinder. The channels are hung directly in front of the regular telescopic channels and are operated by a separate control. This extra attachment can be removed for normal fork truck operation.

In other respects, trucks equipped with this device are standard Yale gasoline or electric trucks.

New Miniature Transistor.—The spidery object at the left is the newest type of transistor, a tiny amplifier invented at Bell Telephone Laboratories. For size comparison, it is shown with a minature commercial vacuum tube which does about the same job. Transistors have been called the first serious rival of the vacuum tube, and the new type, requiring about a millionth of the power of miniature vacuum tubes, will amplify electrical signals a million



times. Predicted theoretically two years ago by Bell Labs' Dr. William Shockley, the new transistor has astonishing properties never before achieved in any amplifying device. Bell scientists have also developed an improved transistor of the type they announced three years ago, and report that that type, now as uniform in performance as vacuum tubes, will be put into trial use in the Bell System early next year.

World Metallurgical Congress.—More than 100 of an expected 150 major American industries, research laboratories and experimental stations already have accepted the invitation of the American Society for Metals to play host to top metal scientists of other nations who will attend the World Metallurgical Congress in Detroit, October 14 to 19.

The American Society for Metals is sponsoring the Congress and arranging the so called "Study Tours" of industrial centers. The tours will travel primarily in the Northeastern United States from September 17 to October 13.

More than 290 key metal scientists—or "conferees", as they are called—from 21 Marshall Plan and other free nations have been selected for tours by the State Department and the Economic Cooperation Administration. Individual teams of the visitors will visit more than 60 cities in 13 states, viewing at first hand American production and conservation methods in the metal industry. Tour itineraries are being arranged by the American Society for Metals and World Congress officials.

The Study Tours will converge in Detroit for the World Metallurgical Congress, October 14–19, and the concurrently held 33rd National Metals Congress and Exposition, both A.S.M. sponsored projects. The Detroit affair will be the first world gathering of metal scientists and production chiefs and the largest industrial congress ever held anywhere. More than 40,000 persons are expected to register individually at the meeting.

Members of the Tours will disembark in New York on September 13th and be welcomed to America at a Waldorf Astoria Hotel luncheon on September 17. They will visit essential industries along the Eastern seaboard en route to Washington where a meeting with President Truman on September 21 is anticipated. From there they will break into specialized groups for the tours across the nation.

According to the spokesmen, special liaison representatives between the World Metallurgical Congress and various Government Departments have been appointed by Defense Mobilizer Charles E. Wilson, The E.C.A., State and Defense Departments and Charles Sawyer and Oscar L. Chapman, Secretaries of Commerce and Interior, respectively.

One of the main purposes of the Congress and its Tours is "to advance metal production and conservation in the interest of national and free world defense."

The Tours comprise 15 to 30 conferees per team and are organized according to interest: 1. Steel making and refining; 2. Rolling and manufacturing of copper, aluminum, magnesium and their alloys; 3. Metal fabrication; stamping, machining and finishing of alloys; 4. Heat treatment; 5. Welding and joining; 6. Inspection and testing; 7. A review of engineering and metallurgical education in the U. S.; and 8. A research tour will visit Bell Telephone, U. S. Steel Corporation and Aluminum Company of America research foundation and laboratories, among others.

Countries represented by conferees on the tours will be: Austria, Australia, Belgium, Brazil, Denmark, Finland, France, Germany, Greece, Holland, India, Italy, Japan, Luxembourg, Norway, New Zealand, Portugal, Sweden, Switzerland, Turkey and the United Kingdom.

A quick and pure water supply for small bodies of isolated troops is assured with an Emergency Water Treatment Unit developed at the California Institute of Technology. In a recent demonstration at the Air Force School of Aviation Medicine, the unit converted raw sewage with a bacteria count of 2½ million per cc. into chemically pure and sterile water. Less than a cubic foot in size and weighing less than 12 pounds, the unit is operated by a simple hand pump; a strainer on an intake hose takes out algae, a chemical filter takes out suspended matter and kills bacteria. The unit will deliver pure water at the rate of two quarts per minute for 30 to 40 minutes, after which the filter must be replaced.